BBC response to Ofcom's Consultation "TV white spaces: approach to coexistence"

Executive summary

The BBC welcomes the opportunity to respond to Ofcom's consultation on TV white space coexistence, published on 6th September 2013 and with an addendum published on 24 October 2013.

Demand for wireless communications is increasing and traditional approaches to spectrum management may face challenges as a result of these changes. In that context, we support the leading role that Ofcom is taking, both at home and abroad, in driving forward spectrum innovation initiatives.

Dynamic spectrum access, in its various forms, may be a key to unlocking spare spectrum capacity to enable a wide variety of wireless services. One of these initiatives is Television White Spaces (TVWS), seeking to make use of interleaved UHF spectrum allocated for broadcasting but unused on a geographical basis as a result of the deployment of multi-frequency networks.

The BBC has two principal interests. Firstly, the interests of our audiences who we seek to inform, educate and entertain. Secondly, value for money for the licence fee payer. A successful implementation of TVWS technology could enhance the service that we provide and open up new avenues of accessing content for our audiences.

However, these positive outcomes can only be realised if existing and highly valued BBC services are not negatively impacted by a flawed introduction of TVWS services. Digital Terrestrial Television (DTT), Programme Making and Special Events (PMSE) and Local TV all currently use UHF broadcasting spectrum. A new service introduced in a way which impairs the enjoyment that citizens and consumers derive from watching TV is clearly one that we need to prevent.

In the case of TVWS, we consider that Ofcom needs to develop its proposals in the context of these being licence-exempt services seeking to co-exist with established lawful users of spectrum. The established legal framework for the introduction of licence-exempt services points to the need for a cautious approach to ensure that those existing services do not suffer undue interference. We welcome further discussions with Ofcom on how it will define what this means in practice and set out some thoughts on this within this document.

Our concerns lie not with the *principle* of TVWS, but over the way that Ofcom is proposing to implement these new services. The proposals are significantly different to the position agreed in Ofcom's technical working group, and as such carry an elevated risk to TV and PMSE services. It is in nobody's interest to introduce new TVWS services if the benefits are outweighed by disruption of the high quality TV services that they previously enjoyed.

In that spirit, we offer our support to Ofcom in developing its proposals for TVWS, ensuring that our audiences do not lose access to their existing services in the meantime. We set out in this consultation response those areas where we believe

Ofcom needs to reconsider its proposed approach to TVWS, thereby ensuring that audiences and consumers are the winners. These are:

- The proposed maximum TVWS power levels appear inconsistent with Ofcom's stated aim to take a conservative approach to introducing these services. As such they pose an elevated risk of harmful interference to existing services and may need to be reduced;

- The lack of provisions for the protection of indoor aerials could affect the reliability of reception on up to 7.5 million TVs currently operating in this mode. This requires further consideration;

- The lack of protection for aerials not pointing at the "best" transmitter could see many TV's also facing unacceptable levels of interference from new TVWS services; and

- The lack of detail as to how any interference events will be reported, how the source of the interference will be identified, what might be the triggers for adjustment of the database parameters and how the changes to the database will be authorised.

Elsewhere in this response we deal with more detailed technical concerns.

Ofcom plans to run TVWS pilots as well as conduct coexistence trials in the near future. The BBC is keen to work with Ofcom and others to assess, as far as possible, the level of risk to existing services.

General points

Background

Freeview is used by over 80% of viewers in some form and provides reliable digital TV reception, free from harmful interference from other wireless services. Uniquely amongst TV platforms in the UK, DTT provides universally available, free-to-air broadcasting services.

In its November 2012 UHF Strategy statement Ofcom affirmed its long-term commitment to the DTT platform. At the same time, it accepted the importance of continued PMSE access to interleaved spectrum and the sector's contribution to the creative industries and the social and cultural well being of the UK.

To support Ofcom in its aims of developing new applications in the TVWS we have devoted considerable technical effort and resources[1]. We recognised the need to understand the necessary technical parameters for successful co-existence between White Space Devices (WSD) and licensed DTT and PMSE and to explore opportunities for potentially valuable new services.

Subsequent CEPT reports[2] addressed technical requirements and the concept of a geolocation database. We worked closely with Ofcom on contributions to all of these reports, developing a UK consensus view for PMSE and DTT protection. The UK contributions, led by Ofcom, were accepted by CEPT. No significant issues were raised during the public consultation phase.

The BBC also contributed extensive practical expertise through participation in real TVWS trials in Cambridge and the Isle of Bute. This involved over two years of measurements on actual TVWS radios with measurements being used to determine the protection ratios required to protect DTT and PMSE from interference from a range of candidate WSD technologies.

We have participated in Ofcom's TVWS Technical Working Group (TWG). A programme of over 35 teleconferences ran from September 2011 to April 2013 where technical aspects were discussed in great detail; topics including WSD coupling geometries, acceptable interference levels, receiver protection ratios and the impact of these parameters on TVWS availability.

Throughout all of these discussions and work programmes, Ofcom explicitly committed itself to a cautious approach to the introduction of TVWS technologies. The protection of DTT and PMSE were viewed as crucial to the on-going work. However, a number of

[1] We contributed to the first round of CEPT studies in working group SE43 from Q4 2009 culminating in ECC Report 159, which was published in January 2011. This work was based on input documents from both industry and national administrations across Europe and defined the initial framework for WSD coexistence with licensed services.

[2] A second programme of work lasting 1year was initiated by CEPT to address issues raised in ECC-159 and this produced reports ECC-185 and ECC-186, which were published in January 2013.

sensible positions appear to be have been abandoned in the latest consultation on TVWS, published on 4 September 2013

Concerns on the September 2013 Consultation

We set out our most significant policy and technical concerns in this section. However, on a general point of detail, we note that Ofcom has opted not to follow its own best practice by failing to undertake an Impact Assessment. This is regrettable, as it may have led to a fuller understanding of the likely impacts of some of its proposals than appears to be present.

More broadly, we are concerned that some critical points of policy *as they relate to TVWS* may have been decided or pre-empted without consultation with stakeholders. There is a general question for Ofcom as to how proper it is to assume that policy positions taken in one discrete policy context should automatically be applied to different areas of policy. This is particularly the case here with the issues of indoor aerials and protecting multiple transmitters.

Finally, we have a concern that the proposals as they currently stand appear to be giving priority spectrum access to licence-exempt services over lawful licensed services. We are not aware of another example of where this has happened in the realms of spectrum management. Furthermore, there may be some conflict with Section 8 of the Wireless Telegraphy Act, which states that licence exemption should only be enacted where Ofcom is satisfied that licensed services will not suffer "undue interference". In the case of 7.5million TV sets using indoor aerials, this appears to have been overlooked.

The need for a more detailed policy framework

Section 8 of the WT Act sets an obligation on Ofcom to introduce licence exempt services only where it is satisfied lawful users of spectrum will not suffer "undue interference". Ofcom appears to take the view within this consultation that the 7.5m TV viewers who use indoor aerials should not receive such protection. However, we believe that this is simply not tenable given the reasonable expectation of continued TV reception from such a significant number of viewers.

To mitigate this risk of interference and in light of the serious consequences of a poor outcome for this very large constituency, we would expect Ofcom to adopt a specifically precautionary approach. In practice, this would mean setting genuinely conservative power levels in the first instance – leaving open the option for relaxing these if and when evidence came to light that this was a prudent course to take.

More broadly, Ofcom is seeking to introduce new services in UHF interleaved spectrum while seeking to ensure a "low probability of interference" into TV and PMSE. It is difficult for us to have an informed view on this objective in the absence of knowing precisely what Ofcom means by this terminology. The key question for Ofcom to consider should be what would be a reasonable risk threshold to DTT and PMSE which would lead to a change in Ofcom's proposed approach for the introduction to WSDs?

Our current view is that the current proposals represent a significant risk to both DTT and PMSE services. In order to help us to assess what changes need to be made to these proposals, we would welcome further discussion as to what it deems to be a "low probability of interference". In particular, what levels of risk it believes is appropriate to take forward sensible proposals for the introduction of WSDs.

Proposed WSD power levels

Given the extensive preparatory work we had undertaken with Ofcom and other stakeholders on WSDs, we were surprised at elements of the September 2013 consultation. The proposals within represent a significant relaxation in the protection of DTT and PMSE in comparison to those agreed in SE43 studies and discussed in subsequent TWG meetings. Despite this, Ofcom maintains throughout that the proposals remain "conservative."

Using the new relaxed parameters, Ofcom has estimated substantial TVWS availability at 4W EIRP, which we feel may be misleading to stakeholders. Over two years of BBC measurement data on DTT receivers, previously validated by Ofcom's Baldock laboratory and accepted by CEPT in report ECC-185, are not considered. Different data has been used instead to calculate availability. However, this does not take into account traffic on real WSD radios. Furthermore the data sets describing the geometries for typical coupling scenarios have been truncated to favour the WSDs.

Tellingly, protection *has* been tightened[3] for IMT services in the LTE-800 band. Here, co-channel and adjacent channel prohibitions have been suggested across the entire UK. This is even though a number of areas will never have access to all 4G services in the band 790-862MHz. In contrast, both co-channel and adjacent channel operation within DTT spectrum is permitted.

Indoor aerials

Of further significant concern to us is the issue of non-protection of indoor aerials. Paragraphs 5.13 and 5.14 of the consultation appear to state that a decision *has* been made to the effect that indoor aerials will receive no protection from new TVWS services. Indeed no views are sought on this position although we now understand from further discussions with Ofcom that this issue may be open to further debate. Proposals had been made to the Technical Working Group detailing how portable protection, where viable, could be protected, with only a small impact on TVWS availability[4], but these have not been considered.

[3] Aligning with CEPT ECC-186 recommendations

[4] "Protection of Broadcast Cells with Mixed Mode Reception using the Database Approach", BBC R&D White Paper WHP 223, April 2012: http://www.bbc.co.uk/rd/publications/whitepaper223

According to a 2011 Digital UK (DUK) report[5], as many as 7.5million TV's rely either on a set top or loft aerial. In many cases, these choices will be driven by problems in accessing a roof-top aerial.

Unlike the circumstances with the recent 4G interference issue, interference from WSDs into indoor aerials is unlikely to be solvable using a simple filter. Indeed, the potential problem in this instance will be aggravated by Ofcom's proposal to allow increased WSD power levels indoors.

We would suggest that it is not tenable to adopt a policy position which results as many as 25% of all TVs facing significantly elevated risks of interference from a licence-exempt service.

Protecting only the "best" transmitter

We are unclear as to whether Ofcom will protect only aerials which are pointing to the "best" transmitter[6] or whether other layers will also be protected. Paragraph 5.19 appears to have made a decision that only the best transmitter will be protected. However, Ofcom has subsequently informed us that other layers will also be protected with calculations elsewhere in the consultation taking this protection into account. We would welcome fuller clarity from Ofcom as to its position.

A significant number of consumers choose not to use the strongest 3 multiplex relay service and opt for a weaker, yet viable, 6 multiplex service offering more content. The parameters chosen by Ofcom may result in co-channel interference to the 6 multiplex services and viewers will need to realign their DTT antennas to the stronger 3-mux services losing half of their Freeview services.

Paragraph 5.20 states "*we do not expect a significant impact on DTT viewers as a consequence of this proposal*". We would be grateful if Ofcom could share with us what it bases this assessment on. This same paragraph goes on to say that in the event that there is a "*significant impact on DTT viewers as a consequence of this proposal… we will consider the need to change the data provided to WSDBs*". We are grateful for this and would request more information on how it will assess the impact on viewers, what it views as "significant" and precisely what measures it would put in place if that threshold were passed.

Key technical concerns

We address fully our detailed technical concerns elsewhere in this response and in the Annex. However, we summarise our broad observations here:

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[5] "Domestic Receiving Systems Set-top and Loft Aerial Usage", Digital UK Technical Note, 26th April 2012

[6] The "best" transmitter for some pixels may carry only half the Freeview services and an alternative, but weaker transmission may offer the full set of Freeview services.

- The acceptable loss of coverage has been set to 7%, based on an edge of service calculation that will be applied throughout the entire DTT coverage area. This erodes 1.1dB from the 2.9dB planning margin at the very edge of coverage and proposes this interference level for the entire broadcast coverage cell. This will allow WSD interference levels that were previously considered unacceptable at the edge for all DTT viewers;

- Receiver performance issues, identified through 2 years of DTT measurements by the BBC, have not been acknowledged. An optimistic set of protection ratios has been proposed instead by considering measurements on a Weightless radio that had been hard wired to generate a benign test signal. This is in no way representative of real M2M or similar WSD applications. The proposed protection ratios favour the WSD by some 20-30dB compared to those accepted by CEPT and under consideration by the receiver community as future DTT receiver performance targets in the DTG D-book;

- The coupling models developed in the TWG, based on statistical analysis of real building separations, have been expressed in a way that has the effect of disguising the issues. Data from DUK has been truncated with a result that WSD have been favoured. This carries a high risk of interference if WSDs are widely deployed as proposed by the M2M industry. The proposed models result in coupling gains that are a significant relaxation from the reference geometry assumptions used in CEPT SE42 and SE43 studies. There is no experimental evidence to justify this approach;

- Ofcom proposes to base all protection on the assumption that an optimum roof top antenna is installed at 10m height. This ignores evidence from DUK[7] that many households rely on loft installations for reception. We are also concerned that many households install antennas at a reduced height in strong signal areas (such as bungalows or on those houses where it may be difficult to mount a 10m antenna);

- The 4W limit may be sufficient to prevent overloading of standard domestic installation but is likely to cause overloading of amplified installations as observed in the Bute[8] trial. Ofcom's own data[9] suggests over 40% of DTT installations may use amplifiers, yet amplifiers are not considered at all in the condoc;

- The protection of PMSE has also been relaxed and the consensus views developed in CEPT SE43, subsequently published in Chapter 5.3 of ECC 186, have been ignored. This is surprising as Ofcom led this work in cooperation with other UK

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[7] "Domestic Receiving Systems Set-top and Loft Aerial Usage", Digital UK Technical Note, 26th April 2012

[8] See pp36-37, TSB100912: Final Report White Space Rural Broadband Trial on the Isle of Bute http://www.wirelesswhitespace.org/media/28341/tsb100912_bute_ws_report_v01_00.pdf

[9] **"**Further modelling of interference from mobile network base stations in the 800 MHz band to digital terrestrial television ", Peter Faris, Haibin Li, Reza Karimi, 3 October 2011

stakeholders, including the BBC. The proposed coexistence parameters potentially degrade PWMS link budgets by up to 40dB. The protection ratio measurements on IEMs appear erroneous, suggesting the stereo decoder was disabled. We also note that the overload characteristics have not been measured;

- The proposals to test coexistence parameters through the pilots will require careful planning given the absence of sufficient WSD radios to operate in the band. A large-scale trial appears necessary but the WSD industry is not yet ready to support this. As a consequence, there is a risk that insufficient equipment will be deployed to cause interference in the pilot. This means that the statistical nature of the coexistence parameters cannot be evaluated. On this basis, Ofcom's plan to introduce services based on this framework by the end of 2014 is very optimistic. It potentially carries a high risk of interference to the incumbent services unless more cautious co-existence parameters are chosen; and

- Ofcom has not developed any proposals on how interference should be monitored and it is apparent that existing processes may be inadequate. For example, there are no mechanisms for sharing details of WSD use with the BBC's interference helplines. The consultation accepts that new approaches will be necessary, but there are no proposals on how this would be addressed.

In addition we believe that there are some errors in the calculated availability plots. This principally affects Figure 4.15 in the technical report, where some of the plots show far more availability for 30+ channels than we would expect, given that 9 channels should be protected in the London area (allowing for the PSB, COM, 600MHz and local multiplexes as described).

Finally, we believe there are some errors in both Figure 4.14 and 4.15, namely:

- The vertical axis legend should read "Percentage of households" throughout Figure 4.14; and

- Figures 4.14a and 4.14c appear to be swapped; the same applies to 4.15a and 4.15c.

We understand that Ofcom has already been made aware of at least some of these issues. However other stakeholders should also be aware of these issues in case it affects broader policy conclusions.

Responses to questions

(Q1) Do you have any comments on our proposed approach to ensuring a low probability of harmful interference to DTT services? Please state your reasons for your comments.

1. The parameters proposed in this consultation represent a significant relaxation to the position reached in Ofcom's Technical Working Group (TWG). This approach has improved TVWS availability but carries an elevated risk of interference to Freeview services, used by 80% of the population. The published TVWS availability data is misleading for a number of reasons:

   a. The statistical approach used to calculate the probability of interference is flawed (see Annex A);

   b. The methodology used to protect the low-power interim 600MHz multiplexes and local multiplexes is unclear and, as such, the published availability is potentially misleading (for example, it is unclear if the coordinated or actual ERP values of the interim multiplexes were used in the calculations). We note the DPSA layers for interim multiplexes and local multiplexes, which are a pre-requisite for any TVWS availability calculation, are still under development;

   c. The availability is based on using DTT reception margins that many consumers have exploited to reduce installation costs. For example, we know that loft mounted antennas (paragraph 5.12) are widely used and may be more vulnerable to interference. Ofcom assumes that consumers will install outdoor antennas at 10m height, even in areas where this was not previously necessary, to prevent against WSD interference.

   d. There will be no protection of portable reception (paragraph 5.16) even though this is the only method of reception for some consumers. This is disappointing, as we had proposed a methodology with a limited impact to WSD availability, exploiting the flexibility of the database approach to give some protection of portable reception, where it can be reliably received in populated areas.[10]

   e. Furthermore, Ofcom states in paragraph 5.16 that the proposals will lower the probability of harmful interference to indoor aerials. However we believe that the lack of protection for indoor aerials could significantly *increase* the likelihood of harmful interference to indoor aerials, because:

      - In-home WSDs are allowed to transmit with up to 7dB more power; and

[10] "Protection of Broadcast Cells with Mixed Mode Reception using the Database Approach", BBC R&D White Paper WHP 223, April 2012: http://www.bbc.co.uk/rd/publications/whitepaper223

- Indoor receivers will naturally be working with much lower signal levels than fixed roof-top aerials, which will make them significantly more prone to interference.

f. Ofcom appears to have chosen to protect just a single DTT transmitter (with the exception of some Nations overlap and overspill from Ireland) without considering overlapping coverage (paragraph 5.19). This takes no account of historical factors and places a burden on consumers to re-align their antennas to the strongest transmitter. We are aware that in areas where a 3-multiplex relay station provides the preferred service, a significant number of viewers will opt for an enhanced receiving installation, pointing at the lower signal level 6-multiplex main station. Use of a single 'preferred' service would result in these viewers losing services. In some cases, consumers may lose half of the Freeview content and their preferred regional service. Ofcom should choose more appropriately from the JPP's (Joint Planning Project) set of DPSAs (Digital Preferred Service Areas) allowing protection of more than a single DTT transmitter. The technical analysis document (paragraph 4.130) states that the 3 and 6 mux DPSAs have been included in the availability data. However, this apparently contradicts the earlier statement in paragraph 5.19 that only one transmitter will be protected. Where coverage overlaps at the edges, use of the "Next Best" DPSA would be appropriate. Further clarification on Ofcom's approach is, therefore, needed.

g. The proposed reduction in DTT coverage from WSD interference is 7%. The margin at the edge of reception will be degraded from 2.9dB to 1.8dB. In strong signal areas the margin will be limited to 8.1dB, even though the errors in the underlying planning model can exceed this value. Significant investments have been made by broadcasters[11] during DSO to improve reception reliability and these proposals could undermine this investment.

h. All calculations are based on interference from a single WSD. No aggregation of interference is considered on the assumption that only a single device can transmit at any instant in time at a particular location. However, this does not take account for transmissions at different frequencies or the aggregation of noise-like interference from WSDs in far pixels. CEPT approaches to address this issue have been ignored[12].

2. We note that Ofcom has justified its proposed interference budget using a 1dB rise in the DTT interference and receiver noise at the edge of the DTT coverage, characterised by a location probability of 70%. There is no precedent for considering self-interference in co-existence studies and the accepted values defined in ITU BT.1895[13] are based on

[11] http://www.arqiva.com/case-studies/digital-switch-over

[12] See §5.24 ECC-186: http://www.erodocdb.dk/docs/doc98/official/Pdf/ECCRep186.pdf

[13] For licence-exempt devices such as WSDs, an I/N of -20dB is recommended. See http://www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.1895-0-201105-I!!PDF-E.pdf

I/N values that are significantly lower. We note that only a very small number of the pixels served with DTT (typically <1%) have such small coverage margins (2.9dB). It seems inappropriate to use the I/N criterion to calculate the acceptable loss of coverage at the very edge of service and apply this loss of coverage throughout the DTT cell. Selecting the 90% coverage contour would result in a much smaller interference budget. Ofcom's own document 'Planning Options for DSO' refers to 'coverage' and 'marginal coverage' which equate respectively to 90% and 70% of locations. It is inappropriate to apply 1dB erosion to a 'marginal' coverage margin. Furthermore, since the DTT network is largely interference limited, Ofcom's method for relating loss in margin to coverage probability degradation is incorrect.

3. We also note that Ofcom is justifying this proposed approach, in paragraph 5.29, by citing early experiences from the LTE-800 rollout and the DMSL pilots. We feel that extrapolation of DMSL interference reports is invalid for a number of reasons. LTE-800 licence A deployments have yet to be made and the early pilots were confined to high field strength areas[14]. Statements from DMSL regarding interference are premature and not based on robust scientific analysis of the underlying models. It is also worth noting there are no mitigation options for WSD interference, unlike LTE mitigation where simple filters can be deployed. Furthermore, the characteristics of WSD equipment are likely to be significantly different to LTE-BS.

4. DTT aerial installers will typically aim to achieve a 10-15dB margin when installing an antenna. It is unclear on which basis Ofcom has decided to disregard these accepted industry margins by eroding this to 8dB (at best.)

(Q2) Do you have any comments on our proposed approach to ensuring a low probability of harmful interference to PMSE services? Please state your reasons for your comments.

5. The PMSE protection levels listed in Chester 97 and Geneva 06 and used for the analysis in paragraph 6.8a have been superseded by more recent documents. Protection of SAB/SAP at 68dBuV/m (representing a nominal power of -65dBm into a 0dBi antenna) is inappropriate when considering PMSE protection from WSD. Accordingly they were not used in SE43 studies. A figure of -95dBm was proposed in ECC-159[15]. Subsequent SE43 studies recognised the diverse range of PMSE equipment now available such as analogue FM PWMS (mono & stereo); digital FSK / QPSK / MSK; analogue and digital IEMs, analogue and digital talkback. An I/N approach was recommended in ECC-186[16].

6. Ofcom's proposals degrade PMSE link budgets by a value exceeding 30dB. Whilst median signal levels for typical PMSE deployments are *usually* above the sensitivity point of -95dBm, the fading characteristics of PMSE links result in receiver levels which can easily fall to the sensitivity point. Ofcom's protection ratios have been measured in a Gaussian

[14] As reported by DMSL in their 4G roll-out industry presentation, see http://www.dtg.org.uk/projects/4grollout.html
[15] Paragraph 5.13
[16] Paragraph 5.3.4

channel, yet the links operate in a strong Rayleigh channel, characterised by deep fades as microphones move around.

(Q3) Do you have any comments on our proposed approach to ensuring a low probability of harmful interference to 4G services above the UHF TV band? Please state your reasons for your comments

7. Ofcom concludes from its analysis in Section 6 of its Technical Report that mobile-base station interference is likely to dominate protection requirements for a mobile device. As a result, interference from WSDs operating in channel 60 would be significantly lower. Despite this, Ofcom proposes that WSDs should not be allowed to operate adjacent to the primary service (mobile). This contrasts starkly (and inconsistently) with DTT where both adjacent and co-channel operation would be allowed.

8. The proposal to prohibit WSD access to channel 60 is consistent with ECC-186 recommendations based on an I/N analysis. We support protection of *all* licensed services and, in line with the provisions of section 8 of the WT Act, recommend the same I/N approach should also be applied to PMSE and portable DTT reception.

9. The flexibility of geolocation could, indeed, allow some use of Channel 60, especially where licence A LTE-800 services are not deployed. We note that only Licence C (awarded to O2) carries a UK-wide coverage obligation. Allowing Channel 60 WSD transmissions in areas where LTE-800 licence A is not deployed (currently the entire UK) would allow increased opportunities for WSDs.

10. Ofcom is proposing to permit 4W type B WSDs. This would allow deployment in close proximity to LTE-UE devices but may result in a risk of overload to the LTE-800 terminal. The out of block limit of -54dBm/100kHz into the mobile downlink channels[17] (-37dBm/ 5MHz) will typically lift the noise floor of the LTE-UE receiver by 1dB (I/N= 6dB) if the coupling gain exceeds -73dB. For a typical scenario, with a 5m separation between an UE and a Type B WSD, the coupling gain would be -45dB, suggesting an I/N of +22dB.

11. A more flexible approach might actually allow WSD in the band 790-862MHz in areas where IMT services are not available (e.g. rural locations). This would allow for local self-provision of broadband services using LTE-800 equipment, which could represent a significant benefit for rural communities. Using the geolocation database it would also be possible to selectively increase protection in LTE licence A areas; this might include power restrictions in CH59 and Ch58 for WSD with poor OOB characteristics (e.g. Class 5 devices).

(Q4) Do you have any comments on our proposed approach to ensuring a low probability of harmful interference to services below the UHF TV band? Please state your reasons for your comments

[17] See EN 301 598 Table 2:
http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.00.00_20/en_301598v010000a.pdf

12. We are not aware of any coexistence studies addressing compatibility of WSD with services below 470MHz. It is unclear why EN 301 598 proposes OOB emissions some 18dB less stringent than that for the IMT band 790-862MHz. The background for Ofcom's proposal to tighten the emissions from WSD into the band below 470MHz by 8dB appears to be based on protection of breathing apparatus alone. Other potentially more susceptible applications below 470MHz appear not to have been considered.

13. Since there is some similarity between applications below 470MHz and PMSE use, we feel it may also be appropriate to restrict OOB WSD emissions in UHF channel 38 in a future revision to EN 301 598. This is discussed further in our response to T19.

(Q T1) Do you have any comments on our proposal to cap the maximum in-block EIRP of all WSDs at 36 dBm/(8 MHz)?

14. We agree with the application of a cap on WSD powers, although we disagree with the specific value of 36dBm/8MHz. The justification for this limit appears to be that proposed in the FCC regulatory framework[18]. We note that the FCC decided to limit 4W operation of fixed WS devices to 2nd adjacent TV channels and beyond, not allowing access to the first adjacent channel to DTV services. For the FCC personal and portable device category, analogous to Ofcom's type B WSD, the FCC restricted EIRP to 40mW for the first adjacent channels and 100mW for second adjacent channel and beyond. These FCC decisions are sensible precautions and we would suggest Ofcom adopt similar restrictions. The justification for these FCC decisions appears to be a combination of RF safety and DTV receiver overload considerations.

15. The FCC concluded that personal and portable devices are likely to operate with their radiating structure(s) within 20cm of a user. A 4W device operating in this way develops an E field of 55V/m, excluding near field components. This represents an RF exposure level that exceeds the ICNIRP[19] reference levels for public exposure of 30V/m at 470MHz. LTE-800 UE devices are limited to a maximum EIRP of 20dBm, which is the same limit, proposed by the FCC for personal and portable WSD. Given this, we feel the FCC restrictions on personal and portable devices should be applied to type B devices.

16. With regard to the DTV receiver overload issues identified by the FCC, the details of the analysis require further review. The FCC limit of 4W (1W into a 6dBi antenna) was on the basis that adjacent channel operation to DTV services would not be permitted and this limit would apply to fixed devices only (analogous to Ofcom's type A devices). To investigate overload issues in a technically robust way, the characteristics of amplifiers used for masthead and loft distribution application need to be considered. This is dealt with in Annex C, which considers third order intercept (TOI) data for fourteen

[18] See FCC-08-260: http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf.
[19] See "Guidelines for Limiting Exposure to Time Varying Electric, Magnetic and Electromagnetic Fields (Up to 300GHz)", International Commission on Non-Ionizing Radiation Protection: http://www.icnirp.de/documents/emfgdl.pdf

amplifiers. We conclude that a 4W limit would not be appropriate for protecting DTT installations, particularly towards the edge of DTT coverage where high gain mast head amplifiers are likely to be deployed. Given the experience from LTE-800 roll out, where interference to amplified systems has been the primary mechanism causing loss of reception, further analysis and a lower EIRP limit would be appropriate. Prohibiting access to adjacent channels, following the FCC rules, appears to be essential for devices deployed in the vicinity of DTT installations.

17. 4W WSD operation is likely to result in significant interference to indoor installation, including set top reception. This is particularly the case where an active antenna is deployed. Ofcom has chosen not to protect such installations and it is unclear whether this is fully in line with DCMS policy. Nevertheless, we feel protection should be given so that a WSD user in one property does not interfere with a DTT receiver in an adjacent property.

18. The compatibility of 4W Type B WSDs with Cable TV services is unclear. Cable operators have improved screening of set top boxes and cable modems to address potential interference from LTE-UE operating at 20dBm (maximum). It is unclear if the improvements made are sufficient to guard against interference from 4W WSD.

19. Interference aggregation from multiple devices is likely to result in further increases in interference power. We are concerned that Ofcom has concluded in paragraphs 3.39-3.42 that interference aggregation is unlikely. Although CSMA techniques, in certain circumstances, will prevent devices transmitting at the same time but this is clearly not the case when devices are using independent channels adjacent to the DTT service. Considerable efforts were made in SE43 studies to address this matter (see ECC-186 §5.2.4). Accordingly, we urge Ofcom not to disregard CEPT proposals and to include an appropriate interference margin in an initial deployment.

20. Ofcom is proposing co-channel operation of WSD with protected DTT services. Under such scenarios, spread spectrum techniques (CDMA) would be the only viable technology. Ofcom's suggestions in paragraph 3.41 that CSMA/CA or similar multiplexing techniques would prevent multiple devices transmitting at the same time would not apply if CDMA techniques were used. We prefer to see a prohibition of WSD access to co-channel frequencies to prevent such a risk of harmful interference. In stakeholder workshops, Ofcom indicated that the powers allowed by WSDs operating within co-channel service areas would be extremely low. We would therefore urge Ofcom to adopt a cautious approach and exclude co-channel co-service area use of WSDs.

21. With regard to DTT overload, it is worth noting that the 4W BS equipment deployed on the Isle of Bute TVWS trial resulted in blocking of TV reception in the premises immediately adjacent to the BS equipment at the Kilchattan Bay Exchange. This was remedied by reducing the amplifier gain but it is unclear how such overloading would be addressed in a wide scale deployment of WSDs. For the Cambridge WSD trials EIRPs were typically limited to 125mW due to the limitations of the prototype equipment so there is little experimental evidence to base a 4W limit upon.

(Q T2) Do you have any comments on our proposed approach for calculating WSD emission limits, as expressed in Equation (4.3), in relation to DTT coexistence calculations??

22. The approach suggested is consistent with that agreed by the CEPT in ECC-186 and discussed extensively during Ofcom's Technical Working Group. Our chief concern regards the chosen loss in coverage, of 7%. This represents too large a fraction of a pixel. Ofcom is using the concept of a 1dB rise in interference plus noise at the very edge of UKPM coverage to derive this value. However, despite Ofcom's assertion, we are unaware of any precedent for this in any previous sharing studies. It is common to use I/N values of -6dB or -10dB for co-primary sharing and -20dB for interference from secondary services into primary services. It is not usual, though, to use self-interference within the primary service to relax protection in the way Ofcom proposes.

23. Ofcom has considered pixels at the very edge of the UKPM DTT coverage to derive the proposed reduction in coverage of 7%. A 1dB reduction in margin would reduce the location probability by 6.4%, but Ofcom appears to have rounded this figure up to 7% to further improve WSD availability. The margin of the median field strength above the DTT failure point at the edge of service (70% locations) is just 2.9dB. Ofcom proposes to reduce this margin to 1.8dB, which seems unlikely to be sufficient to provide reliable reception. Ofcom proposes to apply this 7% reduction in location probability across the entire broadcast cell limiting the location probability to 93%. This implies a maximum coverage margin of approximately 8.1dB. We are concerned that this will not prove sufficient to deal with other types of interference within the network (e.g. impulsive interference and LTE). This could affect the reliability and sustainability of the DTT platform.

24. Pixels at the 70% location probability contour represent a tiny fraction (<1%) of the total DTT coverage and most DTT viewers enjoy much larger margins. This is reflected in Ofcom's Consultation 'Planning options for Digital Switchover', where 70% location probability is referred to as a 'marginal service'. If the 1dB approach is to be used, it should not be applied at the 70% LP edge where reception is marginal. A more reasonable approach would be to apply the 1 dB reduction in margin to locations that receive a 'service' with at least 90% location probability. The location variation of the (I+N) at such locations needs to be considered to calculate the equivalent loss in location probability. We set this out in more detail in Annex E.

25. DSO re-engineering work improved the margins within the network by typically 10-13dB and has greatly improved DTT reliability; Ofcom's proposal will potentially reverse this benefit if WSDs are widely deployed.

26. We are concerned that Ofcom's proposals take no account of the finite accuracy of propagation models. The prediction error of the UKPM is understood to have a standard deviation of 7.2dB. This implies for 30% of locations, the prediction errors will exceed 3.8dB and for 10% of locations the errors will exceed 9dB. To suggest a margin of between 1.8dB and 8dB will be sufficient to protect DTT when the accuracy of the predictions can greatly exceed the proposed margins appears dangerous and carries an unacceptable risk of interference. This will inevitably give rise to significant problems in

locations where the UKPM over-predicts the actual median field strength. Additionally, the interference potential of WSDs is calculated using the 'Hata' propagation algorithms. Hata is a statistical method, exhibiting a much greater uncertainty than the UKPM. As a consequence, there is an elevated risk that the use of Hata will underestimate WSD interference. Ofcom dismisses this, stating that Hata overestimates interference. We are unclear what the basis of this assertion is.

27. We tabulate below alternative values for location probability degradation based on the ITU protection criteria for terrestrial broadcasting systems[20]

Sharing Criteria	***I/N***	***70% LP Edge***	***95% LP Edge***
CEPT Report 30: Co-Primary "Least restrictive"	*-6dB*	*6.4%*	*2.1%*
ITU BT.1895 Co-primary	*-10dB*	*2.6%*	*0.82%*
ITU BT.1895 Secondary	*-20dB*	*0.27%*	*0.08%*

28. The ITU co-primary sharing criteria of I/N=-10dB, would imply a 2.6% loss of coverage at the 70% contour. For most pixels, coverage exceeds 95% and such a criteria would imply a 0.82% reduction, close to the 1% figure discussed in the TWG. The ITU secondary sharing criteria of -20dB would give 0.08% reduction at the 95% contour rising to 0.27% loss of coverage at the 70% contour.

29. Our view is that a 1% degradation in coverage would be the maximum acceptable value for introducing WSDs. This is a significant relaxation on the value of 0.08% based on I/N=-20dB from ITU-R BT.1895. This is the value that *should* be applied given that WSDs are licence-exempt devices subject to non-interference provisions to the primary service.

30. There appears to be a small error in the analysis of Annex 1. We describe this in more detail in Annex F to this response.

(Q T3) Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of DTT receivers in relation to DTT calculations?

31. The averaging of WSD EIRP limits (in the dB domain) proposed in paragraph 4.44 for 1st tier geometries could significantly increase the risk of harmful WSD interference. This is likely to occur when adjacent pixels are in different DTT transmitter service areas as defined by the DPSA[21] layers. For further detail, see Annex D. We are also unclear whether the averaging is intended to take place in the linear or log domains.

[20] ITU-R BT.1895. "Protection criteria for terrestrial broadcasting systems (05/2011)": http://www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.1895-0-201105-I!!PDF-E.pdf

[21] Digital Protected Service Areas: These are overlays developed by the UK's Joint Planning Project (JPP) defining which transmitters provide service at a given location.

32. The approach for 2nd tier pixel geometries in paragraph 4.45 does not take account of worst case DTT-WSD separation. Rather, it uses pixel centres. It does not take account of the worst-case discrimination of the ITU-419 template based on the uncertainty of the DTT receiver location within the tier 2 pixels.

33. The centre-to-centre distances proposed for calculating coupling losses for tier 3 geometries again gives increased coupling losses, which favours WSDs. The centre-to-centre approach does not take account of the worst-case antenna discrimination, albeit this does become increasingly less important as separation increases.

34. For tier-3 geometries, the standard deviation on the path loss of the Hata model is discarded which again favours the WSD. It is stated that the Hata sub-urban model will always tend to over-estimate the interference but there is no experimental evidence to justify this statement.

(Q T4) Do you have any comments on our proposed target 1 dB rise in the noise-plus- interference floor at the edge of DTT coverage, and our approach for allowing greater rise in the noise plus interference floor in areas inside DTT coverage?

35. Ofcom's acknowledges the flaw in its treatment of protection ratio and coupling loss as random variables in the addendum to the Consultation. This is discussed in Annex A. We conclude the probability of interference using 70th percentile data values is closer to 30% than the value of 10% that Ofcom originally calculated.

36. Our recommendation to the TWG was that all random variables relating to WSD co-existence should be combined and the WSD power would then be calculated to ensure a maximum loss of coverage of 1%. Should Ofcom wish to continue with their new approach, we believe the percentiles chosen from the distribution of protection ratio and coupling gain should be chosen such that the overall probability of losing 1dB reception margin is less than 10%. The current proposed approach suggests a 30% chance of losing 1dB margin at locations which have only 2.9dB margin. Such locations have "marginal coverage"[22] and it is unacceptable to further degrade this coverage.

37. The proposed approach allows further losses of margin at stronger signal locations. For example, at the 95% location probability contour (corresponding to 9dB margin) Ofcom proposes an erosion of 2.5dB. Given that this is based on a single WSD only, taking no account of multiple devices, and occurs with a probability of 30%, this level of interference is unacceptably high.

38. Applying a 7% reduction across the entire DTT coverage would limit the maximum available margin to approximately 8dB, regardless of signal strength. The proposed losses in coverage are unacceptable and will potentially damage the reliability of DTT reception. There is no precedent for considering self-interference in co-existence

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[22] Marginal coverage was defined in Ofcom's consultation regarding "Planning Options for DSO". See http://stakeholders.ofcom.org.uk/consultations/pods1/

studies and recommendations such as ITU BT.1895 propose sensitivity degradations based on receiver noise and man-made noise only. They do not consider self-interference within the protected service.

39. Ofcom cites experiences with recent LTE-800 services, which launched only a week before the consultation publication date, as evidence that actual interference will be much lower than that predicted. This conclusion is premature. Whilst reported interference from a limited number of 4G-pilots in high field strength areas has been lower than expected, no scientific analysis has yet been undertaken. There are a number of factors which may account for the apparent lack of reported interference from LTE-800 to DTT in the 4G networks deployed so far which include:

    a. The absence of any LTE Licence A deployments which will not launch until 2014;

    b. Less than 10% of the LTE-800 network for Licence B and C have been deployed;

    c. It is unclear what fraction of 4G services are operational in low field strength DTT areas where amplifiers are more common and larger interference holes are predicted;

    d. The coverage losses that Ofcom predicted were based on 1% time DTT interference characteristic of the summer months, yet the 4G network roll out was not started until the 29th August. There remains a risk that the current LTE deployments are consuming margin intended to cope with 1% time DTT interference and viewers may lose service in the summer months;

    e. No LTE pilots were conducted in low field strength areas;

    f. There is an in-complete understanding of the characteristics of LTE-BS idle test signals used for the pilots which has a very significant effect on the required DTT receiver protection ratios;

    g. It is unclear to what extent higher performance BS equipment has been deployed whose OOB characteristics exceed the EC-BEM values used for modelling; this would also result in lower DTT protection ratios and reduced interference; and

    h. It is unclear if LTE BS deployments are yet operating at full power; given the small number of terminals, low power operation appears a possibility.

40. Until there is an improved understanding of these factors, it is premature to draw conclusions on LTE interference, let alone to apply these to the TVWS framework.

41. As discussed elsewhere (see response below to question T2), we are concerned by the impact of errors in DTT predictions, particularly given the small margins that Ofcom is considering for WSD deployment. The DTT coverage models are being used in ways in which they were never intended. All pixel-based models, including UKPM, have a finite accuracy with a typical prediction error standard deviation of 7.2dB. This is inherent in

all pixel based planning models that work with finite resolution terrain and clutter models. The model has been tuned for 0dB error overall, but half the pixels inside the coverage will be over predicted and the other half will be under predicted. In areas where coverage is over predicted, there could be serious consequences for TV viewers.

42. The UKPM model has been tuned by making measurements clear of clutter. In practice, households with good signal strength do not need to take so much care in antenna sighting so may not optimise their installation to achieve the largest possible reception margins. This margin will prove necessary in the proposed TVWS framework.

(Q T5) Do you have any comments on our proposed approach for calculating coupling gains in relation to DTT calculations, including the use of 70th percentile coupling gain values for same pixel, tier 1 pixel and tier 2 pixel scenarios, and the use of median coupling gains for tier 3 pixel (and beyond) scenarios?

43. The proposed coupling models for tier-0 in paragraphs 4.72- 4.74, whilst based on DUK data for household separation data, have been processed in an incorrect way and one which unduly favours WSD. The implications of this flawed approach are discussed in Annex B where we present an analysis of household separations linked to clutter class for the entire UK.

44. The DUK analysis of household separation indicates that the most likely distance between adjacent dwellings was 6m. This applies similarly to rural, sub-urban and urban environments. This follows a simple observation that a row of terraced houses in a rural location has much the same geometry as a row of terraced houses in an urban environment. Ofcom have truncated the DUK distribution data to a value of 5m, 10m and 20m for urban suburban and rural environments, which is not consistent with DUK's survey. By taking account of random DTT antenna pointing using the ITU-419 antenna discrimination template, the truncated data distributions and the associated CDF is made to *appear* more plausible. However, the impact of the truncation is still very apparent in the pronounced knee of the curves shown in Figures 4.10(a) –(c).

45. Ofcom's proposal to use the 70th percentile values for the framework was based on an incorrect assumption for calculating a 10% probability of interference. This is not valid and a value between the 85th or 90th percentile should be used instead to ensure only a 10% chance of interference.

46. Footnote 13 in the Technical Report claims that a WSD installer would create the required coupling loss between a WSD antenna and the DTT antenna on the same roof. Given the low coupling gains assumed, it seems very unlikely that this would be achievable in practice. Furthermore, we are led to believe that WSD devices may become prevalent in ordinary equipment within a viewer's house in such things as smart meters and other M2M applications. Unfortunately, Ofcom's proposals do not seem to account for this.

47. For tier 2 pixel scenarios, the proposed CDF graphs (Figure 4.11) do not show the "knee" problem. However, using the 70th percentile value is again incorrect due to the flawed statistical treatment.

48. For tier 3 pixel scenarios, Ofcom proposes to neglect the standard deviation of the Hata model and claims, paragraph 4.92, that the model over-estimates path loss compared to ITU-R 1546. We know of no experimental evidence to justify this statement and indeed Ofcom's own measurements[23] obtained during the LTE trial in Tamworth indicate that the path loss measurements were distributed symmetrically about the Hata model prediction. Given this, a standard deviation of 7.75dB for the Hata model should be used when predicting interference from tier 3 geometries s suggested in the TWG. Path loss predictions using Hata suburban and ITU-1546 are in close agreement for 50% time and both models are "flat earth" models, which do not account for terrain. ITU-1546 is more sophisticated than Hata as it attempts to account for ducting and propagation over water but these are not generally relevant to WSD studies at short distances.

49. For type B devices, Ofcom assumes a 7dB fixed building penetration loss and proposes to allow a WSD increase of 7dB EIRP if deployed above 2m. The accepted value for BPL used by CEPT and ITU RRC-06[24] is 8dB with a standard deviation of 5.5dB. Using these values and the associated statistics, 15% of indoor deployment of type B devices would have a building entry loss less than 2.3dB. The impact of interference from indoor type B devices should be derived using a Monte Carlo simulation taking into account the statistics of the building penetration loss.

50. For Type B devices, Ofcom assumes a default height of 1.5m in all cases, whereas for Type A devices, the default varies from 10-30m with the WSD-DTT separation. We are concerned that this could lead to a risk of exploitation, by taking suitable steps to 'qualify' a device as Type B and gain the benefit of the lower default height, which could result in such a device being allowed to transmit with significantly greater power (up to 30dB). This problem could be mitigated to some extent by adopting a 20dBm limit for Type B devices, as proposed in paragraph 15 of this response.

(Q T6) Do you have any comments on our proposed protection ratios in relation to DTT calculations, including the use of 17 dB for co-channel protection ratio, and 70th percentile values for adjacent channel protection ratios?

51. Ofcom commissioned a range of WSD protection ratio measurements from the DTG, which included recordings of the radios used for the Isle of Bute (WiMAX) and

[23] See pages 117–120 "Technical analysis of interference from mobile network base stations in the 800 MHz band to digital terrestrial television", Ofcom Technical Report, 10th June 2011: http://stakeholders.ofcom.org.uk/binaries/consultations/dtt/annexes/Technical-Report.pdf

[24] See paragraph 3.2.2, "Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)", Geneva, 15 May - 16 June 2006: http://www.itu.int/pub/R-ACT-RRC.14-2006/en

Cambridge trials (Neul Weightless). We are unclear as to why the data relating to the disruptive technologies used in real TVWS trials has not yet been analysed. We are concerned that the chosen measurement set, using a Weightless radio configured to give a repetitive 35ms pulse every 100ms, is not representative of a real M2M deployment. Whilst it is possible that BS equipment might be configured in this way, customer premises equipment (CPEs) would transmit sporadically resulting in disruption to DTT tuner AGC circuitry and the need for increased protection ratios. We have documented this issue[25] and shared our own recordings with the Ofcom Baldock laboratories in February 2012. Our measurement approach was validated by comparing the protection ratios measured using the recordings with those obtained using the actual TVWS radios. All CPE WSD signals require increased protection ratios, strongly suggesting that the values analysed by Ofcom are not representative.

52. Ofcom is assuming, in paragraph 4.103, that unwanted WSD OOB emissions will roll off at 10dB per TV channel, using these ACLR values to calculate protection ratios at offsets beyond N+3. This assumption, whilst appropriate for a narrow band base station fitted with a high-Q band pass filter, is not valid for a broadband WSD. The ACLR characteristics at higher offsets will be dominated by amplifier noise and Ofcom's assumption that ACLR will improve at 10dB/ 8MHz is not valid.

53. Ofcom appears to acknowledge, in paragraph 4.104, that the proposed protection ratios used to calculate availability data apply to the low interference category. This is not stated explicitly. It is unclear what values Ofcom is proposing for the medium and high category as the DTG measurement data relating to CPE waveforms has not yet been analysed. To avoid confusing stakeholders, Ofcom should include illustrative WSD availability for the high protection ratio category.

54. Ofcom is not correcting the protection ratios measured in a Gaussian channel to account for real DTT reception conditions (Rician channel). This would be inconsistent with previous Ofcom work.

55. Our measurements have shown that for some Silicon tuners, higher protection ratios are appropriate for lower adjacent channels than for the upper adjacent channels. Ofcom has assumed symmetrical performance, not measuring protection ratios for lower adjacent channels. This is not appropriate, however, for Silicon tuner designs with low side local oscillators as the image channel falls in the lower adjacent channels. Image rejection is typically achieved using an image-cancelling mixer and significantly increased protection ratios are often found.

56. Ofcom's proposed approach for the measurement of protection ratios is based upon observations leading to 'picture failure'. This is usually the only practical approach possible. However, the values used for the calculation of protection should be based on

[25] "Measured DVB-T Protection Ratios in the presence of Interference from White space Devices", BBC R7D White Paper 226, April 2012: http://www.bbc.co.uk/rd/publications/whitepaper226

the Quasi Error Free condition (QEF). The DTG D-Book (and Digital Europe's E-Book) assumes a 1.3dB difference between QEF and picture failure for co-channel noise-like DVB-T signals, and 2.0dB difference for adjacent channel signals. Accordingly, Ofcom should increase its protection ratio values using the accepted correction factors. A further correction factor of 1.1dB to take account of the Rician channel for fixed DTT reception would also be necessary[26].

57. The protection ratios that Ofcom has measured are based on DVB-T operating with a 64-QAM constellation and a code rate of 2/3. However, there are 3 multiplexes in the UK operating with a code rate of ¾. Increased protection ratios would apply for these multiplexes.

58. According to Table A4.2 of the Technical Report, the ACLR of the filtered Weightless radio was 82dB for the first adjacent channel. However, the actual ACLR in Fig. A4.3 appears to be significantly lower. The correct value should be checked and the calculations adjusted accordingly.

59. Table A4.5 appears to be inconsistent with Table 2.2 in the Technical Report. For example the AFLR for Class 1 in the first adjacent channel in Table 2.2 is 74dB, whereas the ACLR from Table A4.5 is 71dB. Equation A4.11 correctly defines the difference between these two quantities as 19dB.

60. In paragraph 4.106, Ofcom proposes that the organisation responsible for the radio technology should provide evidence of the protection ratios that should apply. It will be necessary to have a robust framework and associated eco-system for making such measurements. It is not appropriate to leave this decision solely to the advocate of a particular technology.

61. In paragraph 4.108, Ofcom states that it welcomes measurement data on protection ratios to inform their decisions. We have provided extensive data to Ofcom based on two years of such measurements. Such data, we now understand, is not considered valid as it used recordings of WSD signals replayed using high quality RF signal generators. Our measurements were validated using comparisons with real radios, and the decision to use recordings was necessary to facilitate automated measurements and to allow cross-checking between different organisations. We had previously understood that our approach was acceptable and had been validated by Ofcom's Baldock laboratory. CEPT also accepted our data in Report ECC-186. Ofcom's new position is, therefore, baffling. It has used the BBC WiMAX BS recordings to determine the PMSE protection ratios, so the approach appears inconsistent with the DTT measurements. We understand that the use of a recording may not be entirely appropriate for a WSD manufacturer to gain approval for technology to be classified in the 'low' or 'medium' protection categories. On the other hand, there is no reason why such recordings

[26] See A3.11: "Technical analysis of interference from mobile network base stations in the 800 MHz band to digital terrestrial television": http://stakeholders.ofcom.org.uk/binaries/consultations/dtt/annexes/Technical-Report.pdf

should not be used – and, indeed, would not be eminently sensible - for an initial establishment of these categories.

62. The proposal to use a co-channel protection ratio of 17dB is based on measurements made with a WSD operating at 35% duty cycle. This may not be correct for WSDs operating at higher duty cycles and does not account for DTT reception in a Rician channel. In practice, higher protection ratios may be appropriate and we propose that further measurements are necessary.

(Q T7) Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of WSDs in relation to DTT calculations?

63. The approach suggested appears satisfactory.

(Q T8) Do you have any comments on our proposed approach for calculating WSD emission limits, as expressed in Equation (5.2), in relation to PMSE coexistence calculations?

64. Ofcom has rejected the I/N approach agreed by CEPT in ECC-185[27]. This approach was based on Ofcom-led UK contributions into SE43. Ofcom is now suggesting that PMSE links are subject to high levels of interference and, therefore, I/N considerations are inappropriate. However, there is no evidence to substantiate this. Furthermore, the comments on PMSE interference levels are not consistent with our experience. We routinely operate PMSE links in the UHF band down to the equipment noise floor. The approach proposed in ECC-185 attracted no objections during the public consultation phase of ECC-185. We are unclear why Ofcom is now proposing to disregard this sensible approach.

65. Ofcom's Technical Report[28] states that a PMSE assignment straddling two DTT channels should be treated as though it were in an adjacent channel to a WSD device operating in either of the two DTT channels. This is not correct. It should be treated as co-channel. Ofcom's co-channel protection ratios used WiMAX recording of 5MHz bandwidth, implying a guard-band between the edge of the WSD signal and the PMSE of 5.5MHz for the adjacent channel measurements. This will tend to underestimate the WSD interference when a PMSE is operated on the edge of an 8MHz-wide WSD signal (e.g. Weightless BS) and higher protection ratios are appropriate.

(Q T9) Do you have any comments on the PMSE wanted signal power levels that we propose in relation to coexistence calculations?

66. We do not feel it is appropriate to reduce the PMSE link budget by 30dB in the way suggested. PMSE devices operate in Rayleigh fading channels. To use a median power level combined with protection ratio data measured in a flat Gaussian channel is not a valid approach.

[27] Paragraph 5.31
[28] Footnote 22

67. We would prefer Ofcom to adopt the more appropriate I/N based approach to PMSE protection developed in the CEPT. In Ofcom's current proposals, it is unclear how the margin should be set. This clearly needs to take account of the Rayleigh fading on the PMSE channel but it is unclear how this would be achieved. The I/N approach avoids this problem and we, therefore, suggest an I/N of 6dB for coexistence calculations.

(Q T10) Do you have any comments on our proposed approach for calculating coupling gains in relation to PMSE calculations?

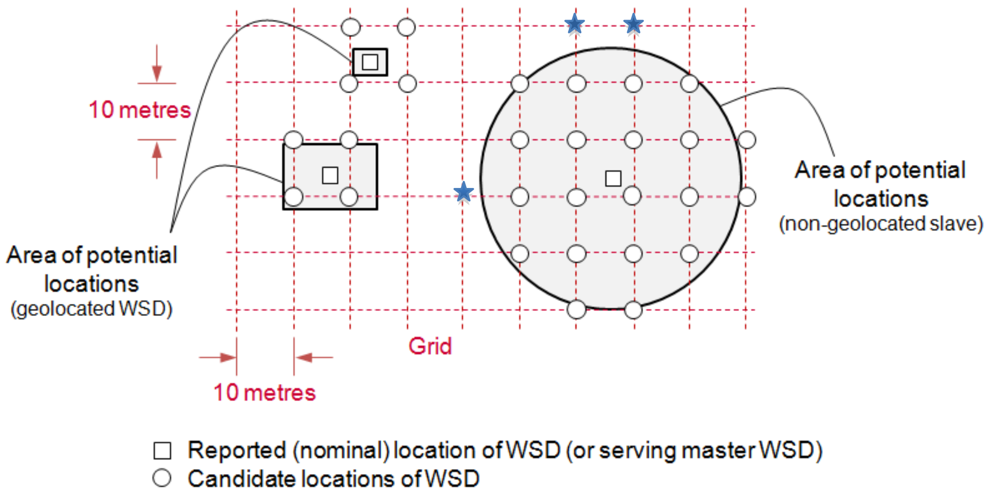
68. We question the assumptions regarding building penetration loss. It is incorrect to assume a building will *always* provide 7dB screening and that the path loss between an indoor WSD and an indoor PMSE assignment will be 14dB higher than for the outdoor case. Building entry loss should be modelled as a lognormal random variable with 8dB loss and 5.5dB standard deviation. The 15th percentile building entry loss is thus 2.3dB. This can be understood by taking account of variations in building construction and the presence of windows.

69. The distance between a non-geolocated slave WSD and a PMSE antenna is assumed to always exceed 10m. However, this value seems excessive. It is possible for a WSD to be in closer proximity to a PMSE antenna mounted at a height of 5m. A value of 5m might be possible in practice for the case of type B devices used by an audience.

70. We support the proposal to use a default WSD type A height of 30m for cases when the height is not reported. It is our understanding that LTE-800 masts are typically deployed at 30m to maximise the mobile cell size.

(Q T11) Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of WSDs in relation to PMSE calculations?

71. This approach appears acceptable. However, we do caution that if this approach is followed carefully, Fig. 5.4 appears to show some locations that should be treated as potential WSD locations that have not been correctly marked. We show this as marked with a star below:



(Q T12) Do you have any comments on our proposed approach for dealing with the uncertainty in the locations of PMSE receivers in relation to PMSE calculations?

72. The location of antennas within TV studios may be moved to suit the set used on a programme and may not be known to 10m accuracy. IEMs are mobile PMSE receivers, which may roam over a large area. ENG applications use wireless cameras equipped with PWMS receivers, which are again highly mobile. It will be necessary to describe a PMSE event by a polygon and accept that the receivers may be deployed anywhere within the area of that polygon.

(Q T13) Do you have any comments on our proposed approach for the derivation of WSD-PMSE coupling gains for non-geolocated slaves in relation to PMSE calculations?

73. If the coverage area of a master device overlaps the polygon describing a PMSE event then it must be assumed that the slave WSDs might be located within the boundary of the PMSE event. To assume an arbitrary separation of 10m between a WSD and the PMSE receiver appears to improperly favour the protection of the license-exempt WSD service over that of the licensed PMSE.

74. The proposals do not appear to take account of reverse IMD. It is necessary, therefore, to consider the proximity of WSD to wireless microphones. Prohibiting access to spectrum for WSD on any channel within a polygon that describes the area of the PMSE would appear to be the only viable solution.

(Q T14) Do you have any comments on our proposed protection ratios in relation to PMSE calculations?

75. Ofcom assumes that devices will exceed the OOB emissions of EN301-598 for offsets beyond N+3 and assumes, in paragraph 5.74, a roll off of 10dB per channel. There is no experimental evidence for this and we feel the OOB characteristics of wide band WSD at larger frequency offsets will be dominated by the wideband transmitter amplifier noise. The roll off of 10dB/ 8MHz channel might be appropriate for an LTE-BS or a similar device fitted with a passive band-pass output filter. It is not, however, appropriate for a broadband WSD. As a consequence of this, we believe it is not appropriate to neglect interference at offsets beyond N+10.

76. The protection ratios are assumed to be independent of level and Ofcom does not consider the overload characteristics of a PMSE receiver. This is clearly not appropriate if it is proposed to allow 4W WSD in close proximity (<10m) of a PMSE receiver. It is of particular concern for in ear monitor (IEM) use as the coupling distance to WSD are potentially very small (e.g. a presenter with an IEM interviewing a member of an audience). The overload characteristics of battery powered receivers used in IEM applications is likely to be significant. Our own measurements show PMSE receiver overload occurs between -20dBm and 0dBm depending upon the design. A 4W WSD operating 10m from a PMSE receiver, such as a radio microphone receiver or a wireless camera, will overload the radio microphone receiver.

77. The protection ratios tabulated in Table 5.5 and Table 5.6 are somewhat surprising. IEM receivers are battery-powered designs using Zenith GE stereo coding which is known to be less robust than traditional FM-mono systems[29]. We would expect the protection ratios for an IEM to be consistently higher than for a mono FM-radio microphones and this is not apparent in Ofcom's measurements. This suggests that the stereo decoder may not have been enabled for Ofcom's measurements, which is not representative of typical operational use. When the BBC conducted protection ratio measurements on PMSE equipment[30], we observed a spread in co-channel protection ratio between 6dB and 8dB depending upon the PMSE receiver type. Digital radio microphones required higher protection ratios than analogue designs. Traffic levels also affect the protection ratios also; for example idle LTE signals, which have a lower average power, require lower protection ratios. We believe it is necessary to use the worst-case traffic loads to determine the necessary protection ratios and based our recommendations on LTE-100%.

78. We are of the view, given the huge variety of PMSE links, that an I/N approach to protection is the only viable method. A protection ratio-based approach will require characterization of a much larger ranger of equipment so a robust statistical approach can be taken. Such measurements will be very time consuming and are not necessary if an I/N approach is used.

(Q T15) Do you have any comments on our assessment that a margin for uncertainties in radio propagation is not necessary given the proposed parameters for derivation of coupling gains in relation to PMSE coexistence calculations?

79. Ofcom proposes to provide no margin in the coupling calculations and to assume Hata will tend to overestimate the path loss; this favours the WSD at the expense of the licensed PMSE service. WSD deployments on hills will clearly give rise to coupling gains that approach free space and exceed the values calculated using Hata. Ofcom's proposal for a 0dB margin is unacceptable. An I/N approach avoids the need to consider margins for different PMSE systems.

(Q T16) Do you have any comments on our proposed WSD emission limits in relation to PMSE use in channel 38?

80. We foresee problems operating channel 38 radio microphones in the vicinity of WSD and are concerned that the adjacent channel restrictions proposed by Ofcom will not be sufficient to preserve link performance.

[29] Stereo FM systems require C/N values up to 14dB higher than mono systems and exhibit protection ratios up to 25dB higher. See Table 2 (p1) and Figure 1 (p3) of ITU-R BS.412-9: http://www.itu.int/dms_pubrec/itu-r/rec/bs/R-REC-BS.412-9-199812-I!!PDF-E.pdf

[30] "Initial Considerations for Protection of PMSE", BBC R&D White Paper 224, April 2012: http://www.bbc.co.uk/rd/publications/whitepaper224

81. A channel 38 wireless microphone receiver may operate on an ENG camera at a distance of 10m from a class 5 WSD tuned to channel 39. Ofcom proposes a WSD power limit of 11dBm. Given the AFLR of 43dB for a class 5 device, the co-channel interference to the PMSE receiver will be -32dBm/100kHz. The noise floor of a PMSE receiver is typically 118dBm/100kHz, assuming a 6dB noise figure. For a 10m separation and an associated coupling gain of 50dB, the I/N at the PMSE receiver will be +36dB. This is unacceptably large and will degrade the performance of the PMSE link. In practice shorter separation distances between a WSD and the mobile ENG camera are quite possible, suggesting an even higher I/N value. Class 1 devices will be permitted to operate at 36dBm, which is sufficient to overload the PMSE receiver. Given an overload threshold of -20dBm and a 5m separation between a WSD and a PMSE receiver, a WSD EIRP limit of 22dBm would be appropriate.

82. In light of the above, we feel it may be necessary to reduce the emission levels from WSDs by up to 40dB to ensure protection of channel 38 PMSE.

(Q T17) Do you have any comments on our proposal not to permit WSDs to operate in channel 60?

83. This is consistent with ECC-186 proposals based on I/N considerations.

84. Ofcom is permitting 4W type B WSDs which may be deployed in close proximity to LTE-UE devices. This may result in a risk of overload to the LTE-800 terminal. The out of block limit of -54dBm/100kHz into the mobile downlink channels[31] (-37dBm/ 5MHz) will typically lift the noise floor of the LTE-UE receiver if the coupling gain exceeds -73dB. For a typical scenario, with 5m separation between an UE and a type B WSD, the coupling gain would be -45dB, suggesting an I/N of +22dB. This suggests there is a risk of interference to LTE-800 from WSD and the values specified in EN 301 598 may not be adequate.

85. A more flexible approach might actually allow WSD in the band 790-862MHz in areas where IMT services are not available. This would allow for local self-provide of broadband services using LTE-800 equipment, which would be a significant benefit for rural communities.

(Q T18) Do you have any comments on our proposal that, if the unwanted emissions limit (over 230-470 MHz) in the draft ETSI standard (EN 301 598) is tightened by 8 dB, there should be no further restrictions on the operation of WSDs in relation to services below the UHF TV band?

86. The analysis seems confined to studies of breathing apparatus and we feel other applications below 470MHz should also be included. Ofcom assumes a 10dB/8MHz roll off of WSD emissions in its calculations in paragraph 7.24, which is not appropriate for

[31] See EN 301 598 Table 2:
http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.00.00_20/en_301598v010000a.pdf

broadband WSD devices. We recommend measurements that are conducted on real WSDs before making such assumptions about OOB performance.

87. The proposal to tighten the OOB emissions of WSDs to -44dBm / 100kHz requires a coupling loss of 74dB for an I/N of 0dB. This corresponds to a separation between WSD and a victim receiver in the UHF1/2 band of 250m using a free space model. At typical separations of WSD, perhaps 20m, the link budget of victim receivers is likely to be eroded significantly.

(Q T19) Do you have any comments on our proposal that, if unwanted emissions limit (over 230-470 MHz) in the draft ETSI standard (EN 301 598) is not changed, there should be restrictions on the in-block powers of WSDs in channels 21 to 23?

88. The power restrictions suggested make an assumption that the out of block emissions will decrease pro-rata with the in block emissions. In practice, many WSDs implement power control in the digital domain by reducing the signal into the modulator DAC. In this case, the out of block emissions are dominated by amplifier noise and quantisation noise and would not decrease pro-rata with the in-block emission.

89. The proposed changes attempt to meet the -44dBm/ 100kHz limit proposed through reductions in in-block emissions. The separation distance of 250m discussed in T18 would apply in this case also. We note LTE-800 UE devices are required to meet an OOB limit of -50dBm/8MHz into the UHF band to protect 10m antennas and a limit of -65dBm/8MHz was suggested for antennas at 1.5m[32]. The limits of -44dBm / 100kHz (-25dBm/8MHz) proposed by Ofcom appears to be between 25dB and 40dB too high.

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[32] http://www.erodocdb.dk/Docs/doc98/official/Pdf/CEPTRep030.pdf

Annex to BBC response to Ofcom's Consultation

"TV white spaces: approach to coexistence"

Annex A

Analysis and implications of the error in Ofcom's proposal for the calculation of the WSD EIRP

Background

In its consultation published on 4th September 2013, Ofcom proposes a method of computing the maximum power radiated by a WSD so as to keep interference to DTT to a given level. This approach is different to its previous suggestion, which was debated extensively within the WSD TWG.

As well as disagreeing with a number of underlying assumptions, we have identified a significant error with the newly proposed approach, which over-estimates the permissible WSD EIRP. The consultation concentrates only on the effect of this error, and does not address our concerns with the underlying assumptions.

Analysis

Ofcom proposes that the EIRP of a WSD must be such that there is only a 10% chance of deteriorating DTT coverage probability of nearby pixels by 7% (paragraph 4.53). It suggests that the maximum permitted WSD EIRP should be estimated by performing two steps:

- The computation of the WSD interference level (U) that causes a 7% reduction in DTT coverage probability; and
- The second step sets the WSD EIRP to a level so that U is exceeded with only a 10% probability. This is achieved by selecting the reference DTT-WSD coupling gain as well as the reference protection ratio to such values so that:

$$\Pr\{rG > r_T G_T\} = Pr\{r > r_T\} Pr\{G > G_T\} \qquad \text{(a1.0)}$$

In other words, following Eqn 4.5, they combine G and r in a single random variable rG and set the combined $r_T G_T$ threshold to the 90th percentile of the corresponding cumulative distribution.

In order to compute the individual values of r_T and G_T, the second part of Eqn 4.5 is used:

$$\Pr\{rG > r_T G_T\} = Pr\{r > r_T\} Pr\{G > G_T\} \qquad \text{(a1.1)}$$

This is incorrect. The right hand side of equation 1.1 calculates the probability that both r exceeds r_T and G exceeds G_T:

$$\Pr\{r > r_T\} Pr\{G > G_T\} = Pr\{(r > r_T) \times and \times (G > G_T)\} \qquad \text{(a1.1)}$$

However clearly there are values of $rG > r_T G_T$ where either (but not both) $r \leq r_T$ or $G \leq G_T$.

As a consequence of the incorrect formula from equation a1.1, Ofcom suggests that r_T and G_T could be such that they are exceeded by r and G with a 30% chance. It is now clear this is incorrect, and we will show that if r_T and G_T are set to the 70th percentile of the cumulative distributions of r and G, $Pr\{rG > r_T G_T\}$ will be much higher than 10%; in some cases exceeding 30%[33] . We will show that in order to be consistent with Ofcom's 10% criterion, $r_T G_T$ could be significantly higher than the value that Ofcom proposes. In many cases this could be higher than 10dB. As a result the permissible WSD EIRP should be also be that much lower.

The simulation

In order to test the magnitude of this error with the distributions applicable in this case, we extended the Monte Carlo simulation described by Ofcom in paragraph 4.75. We considered the same-pixel case only, and focused on a WSD height of 10m. We used the household separation distribution presented in Figure 4.9 and considered Free Space path loss.

For the sake of a direct comparison, distances shorter that 5m were ignored, though we do not agree with the principle of truncation of the household address data. Furthermore, we assumed that each household will have one of the 50 DTT receivers presented in Annex 4 of this document. The selection was random and sales figures data were not included. We then computed the combined rG value for each sample and plotted the cumulative distributions.

The cumulative distribution of the gain G is almost identical to that of Figure 4.10(a) and is shown as a reference in Figure a1. The 70th percentile for G is close to -47dB, which is in line with the value provided by Ofcom in table 4.1(a) (10m case, urban).

[33] This is not a paradox. For example, the chances of a dice throw to give >3 are 50%, but the chance of two dice giving >6 are NOT 25% but 58.3% (which is larger than the 50% probability of a single dice).

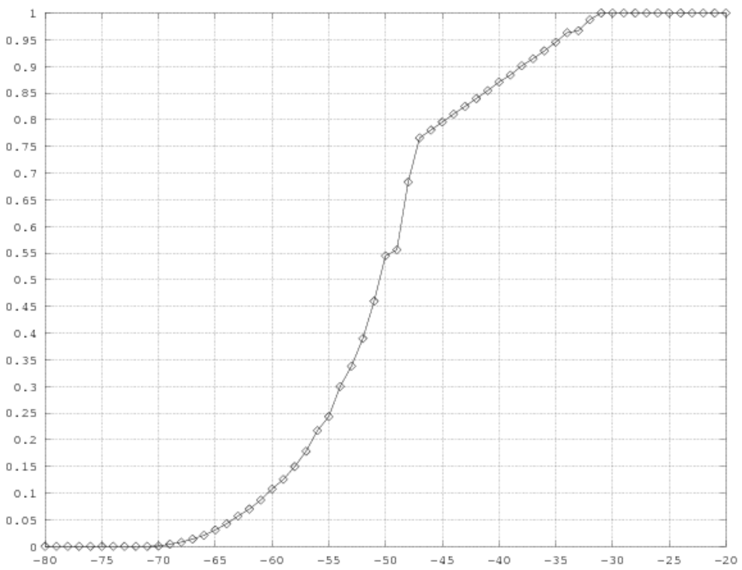


Figure a1: The cumulative distribution of G

<u>Results</u>

<u>Analysis for Wanted Signal = -60dBm, ΔF =80MHz (10 channels)</u>

The protection ratios were taken from the last column of table A4.8 (p138). The CDF of the protection ratio r is shown below in Figure a2 below and the CDF of the combined distribution is shown below in figure a3. We can see that the 70th percentile for the protection ratio is close to -58dB, which is in line with Ofcom's value in table A4.16. Following Ofcom's proposal (paragraph 4.54), $r_T G_T$ should be -47-58 = -105 dB.

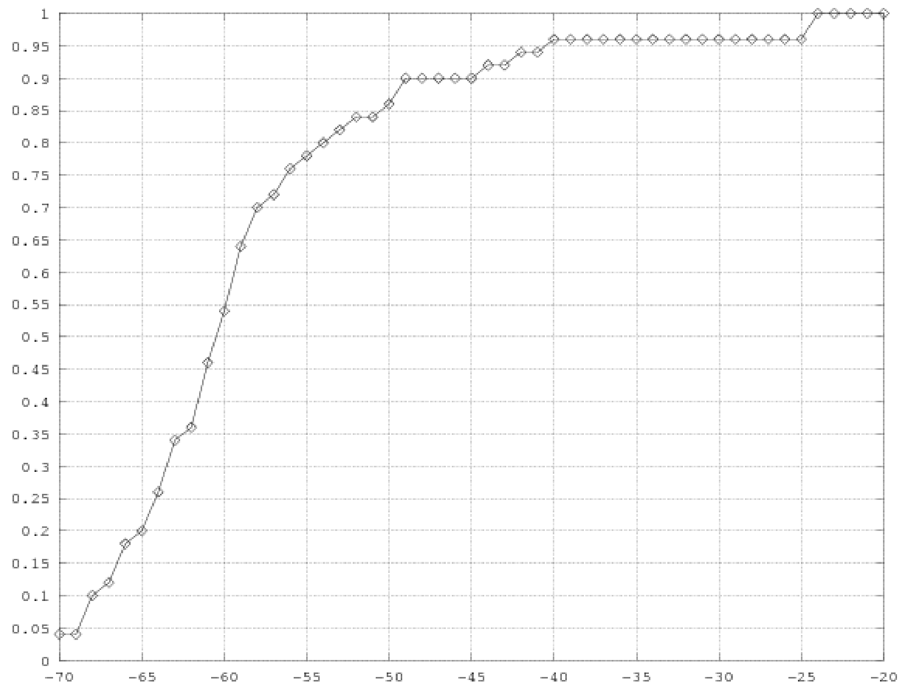


Figure a2: The cumulative distribution of r, C=-60dBm, Δf=80MHz

Figure a3 below shows the CDF of combined rG random variable. Looking up the -105dB value, we see that it is exceeded in 33% (rather than 10%) of the cases. The value that corresponds to the 90th percentile is -92dB, which will allow 13dB less WSD EIRP.

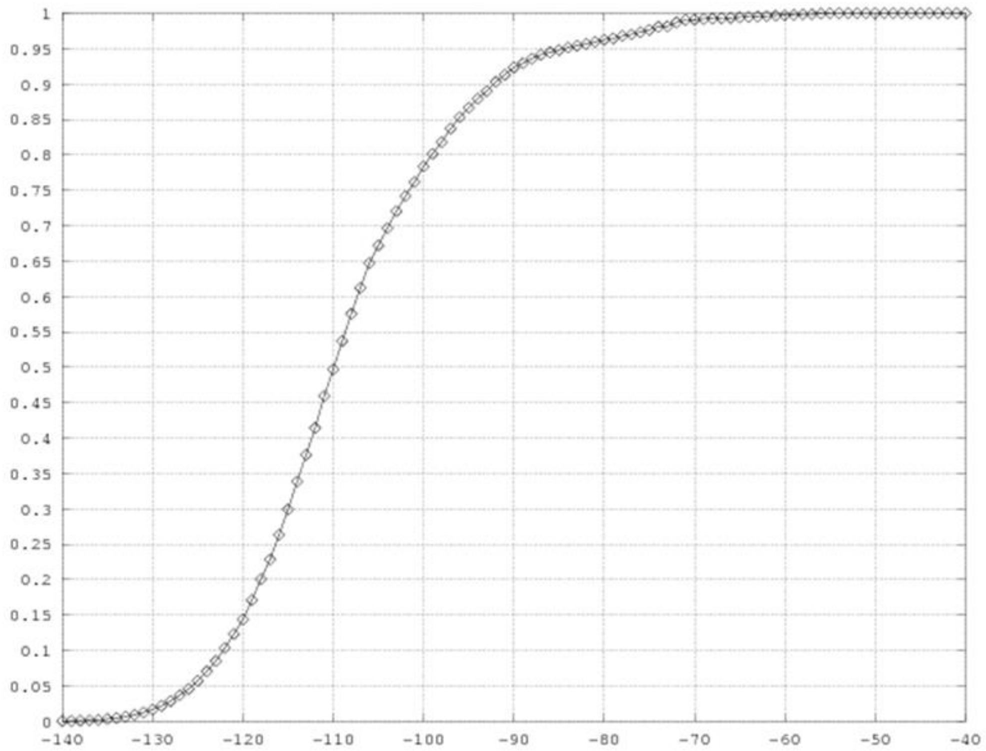


Figure a3: The cumulative distribution of rG, C=-60dBm, Δf=80MHz

If we wish to keep the likelihood of exceedance equal, i.e:

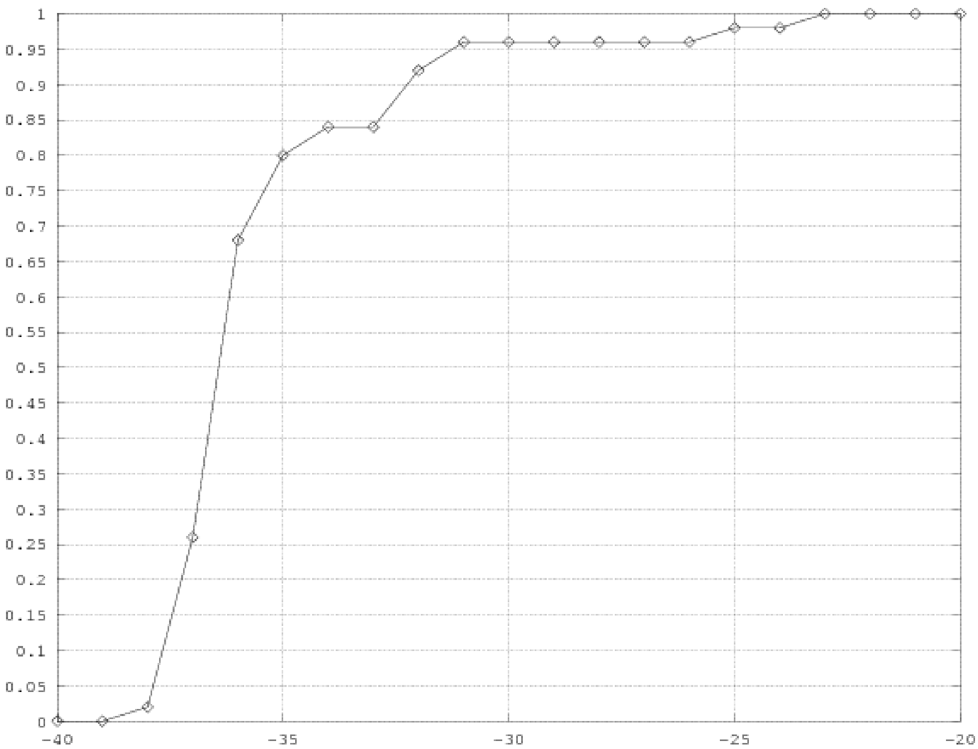
$$Pr\{r > r_T\} = Pr\{G > G_T\}$$

then G_T and r_T should approximately correspond to the 85th percentile of the corresponding CDFs (rather than the 70th percentile as proposed by Ofcom).

__**Analysis for Wanted Signal = -60dBm, ΔF =8MHz (1 channel*)***__

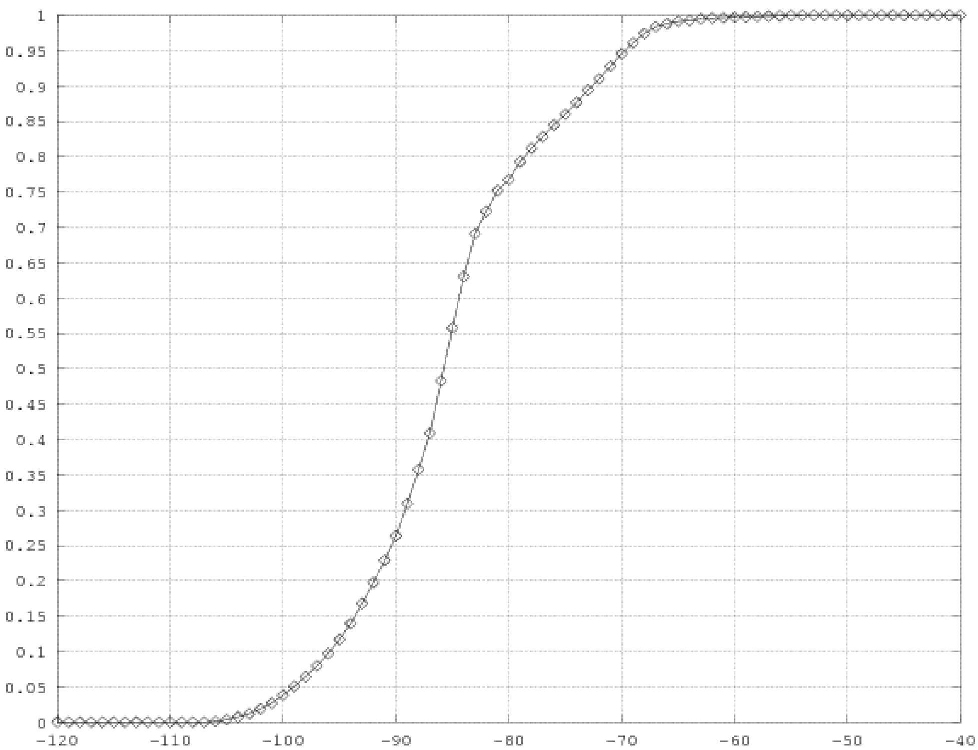
The protection ratios were taken from the second column of table A4.8. The values seem to match with those of figure A4.5, and figure A4.15 (black line).

We present the CDF derived from table A4.8 in Figure C1. According to that figure, the 70th percentile is at -36dB therefore following eqn 4.5, $r_T G_T$ should be -47-36 = -83dB.



Protection ratio, r (dB)

Figure a4: The cumulative distribution of r, C=-60dBm, Δf = 8MHz



Protection ratio / Coupling Gain Product, rG (dB)

Figure a5: The cumulative distribution of rG, C=-60dBm, Δf = 8MHz

The CDF of the combined rG is shown in Figure a5. The -83dB value corresponds to the 69th percentile, so it is likely to be exceeded in 31% of the cases. The value which corresponds to the 90th percentile is -73dB which is 10dB higher.

Finally, choosing the 85th percentile for both G_T and r_T is a much better choice in this case as well.

<u>Co-channel and far pixel considerations</u>

The above analysis, including that in paragraph 4.54, only applies in adjacent channel cases. In the co-channel case, the protection ratio is almost constant, therefore the 90th percentile of the gain should be used, i.e. the reference gain must be -38dB for the co-pixel, Δf = 10 channel case.

A similar observation affects the extended Hata model used in the Tier 3 pixels (and beyond). Here Ofcom proposes that the effect of the value of $0.52\sigma_G$, appropriate for the 70th percentile, should be ignored. Ofcom cites an apparent over-estimation of the Hata model. However now, the value of $1.04\sigma_G$ or $1.28\sigma_G$ appropriate for the 85th or 90th percentile (for the adjacent channel or co-channel cases respectively) is clearly appropriate. If the value of σ_G = 5.5dB (assumed by Ofcom) is used, and the $0.52\sigma_G$ that Ofcom allowed for the over-estimation is subtracted, adjustments of 2.9dB and 4.2dB to the median are required respectively.

The BBC does not agree that this value of σ_G is, in fact, appropriate in this situation, and therefore significantly higher adjustments will be required.

<u>Conclusions</u>

Although there is scope for further analysis, it is clear that in order to achieve the "10% likelihood of exceedance" rule set by Ofcom, a number of corrections need to be made to the consultation document before responses can be considered. These are:

- Where both coupling gain and protection ratio are variables with significant standard deviations, the 85th percentile needs to be used instead of the 70^{th};

- Where one of these variables has no significant standard deviation (e.g. the co-channel protection ratio), the 90th percentile of the other needs to be used instead of the 70^{th};

- For far pixels, an adjustment to the median of the extended Hata model needs to be used; attempting to follow the same reasoning that Ofcom have used implies that adjustments of 2.9 dB and 4.2 dB are required for adjacent channel and co-channel cases respectively; and

- Taking into account all of the above corrections, the white space availability curves and coverage maps would need to be re-calculated.

Annex B

Analysis of address separation used for coupling gain calculations

Background

In the technical note, “TV White Space, Address Separation and Housing Density” published on the 31st of October 2012, DUK present some statistical data on Address separations throughout the UK. Ofcom (paragraphs 4.72 – 4.75) has used that data in order to derive the minimum separation between UK households and the statistics of the WSD-DTT coupling gain in Tier 0 and Tier 1 pixels.

In paragraph 4.74 Ofcom suggests that minimum values of 5, 10 and 20m are representative of nearest neighbour line-of-sight WSD –DTT antenna separations in urban, suburban and rural environments. In this analysis we extend the work of DUK by considering ALL UK addresses , and making a distinction between addresses in urban, suburban and rural areas.

Analysis

Using a representative sample of UK addresses, we examined a region of between 100 and 288m from each address, identifying the closest neighbour. Depending on the clutter type of the pixel where the source address is, we made the distinction between separations in urban, suburban and rural areas.

Results

Figure b1 shows the number of addresses compared with the distance to the nearest neighbour. Most of the UK addresses are in areas classed as suburban, and the minimum separation is largely independent of the clutter type.

For further clarity, Figure b2 presents the same data in a normalised form as a percentage of the total addresses in each clutter category. The peak at 5m is clear in all cases. In urban environments, separations tend to be larger, but this may be explained by the presence of larger buildings in those areas.

Finally Figure b3 shows the cumulative data, the percentage of addresses that have at least one neighbour at a distance closer than the abscissa.

This research demonstrates that, by ignoring addresses that have a separation of less than 5m in urban areas, Ofcom is disregarding about 20% of total addresses. In the suburban and rural areas, however, this figure rises to approximately 75% of all addresses.

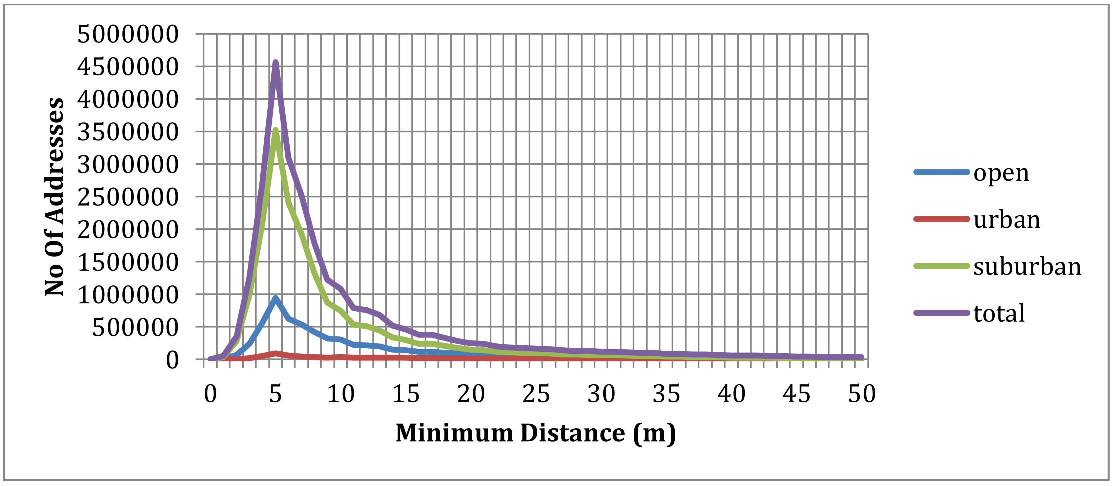


Figure b1: Number of addresses compared with minimum distance to nearest neighbour

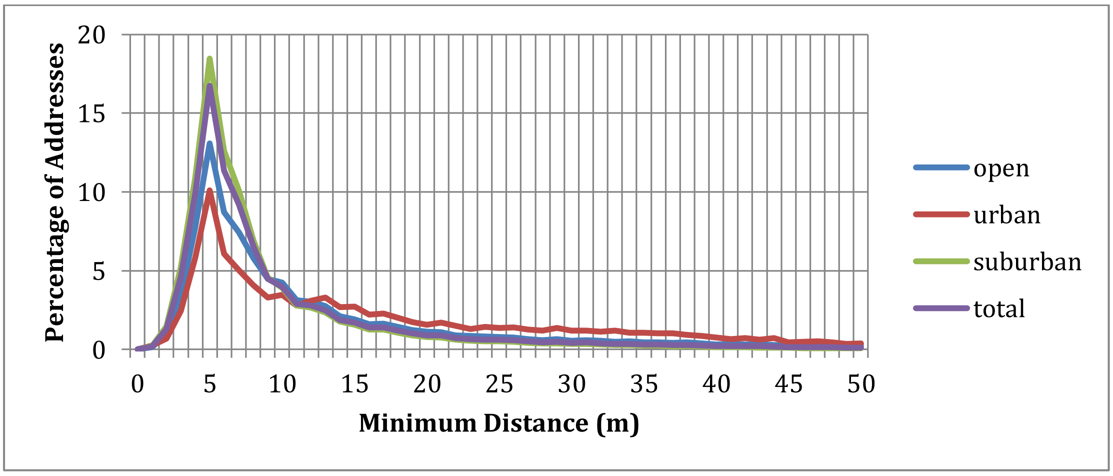


Figure b2 : Percentage of addresses conmpared with minimum distance to the nearest neighbour

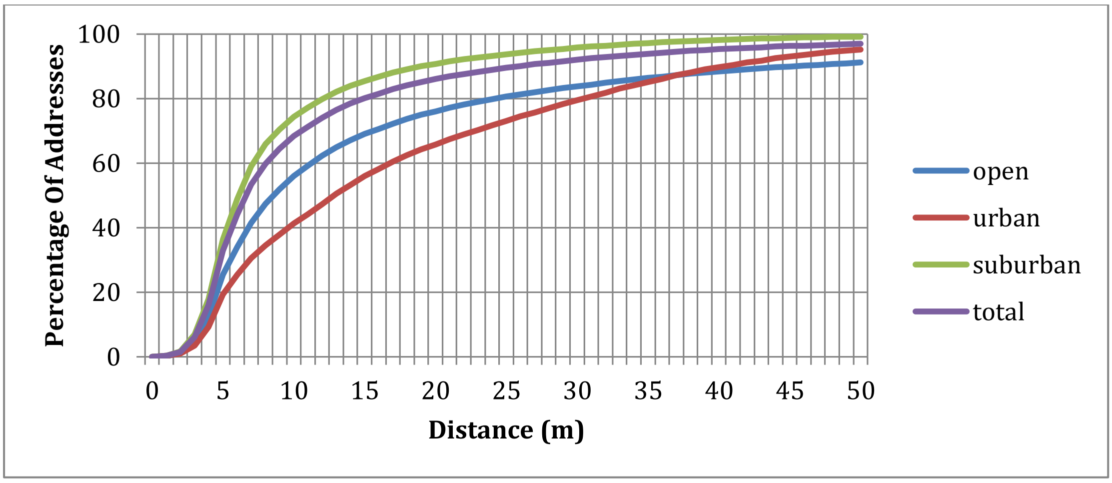


Figure b3: Percentage of addresses that have at least one neighbour closer than the specified distance

Conclusion

Ofcom is ignoring the vast majority of the households which are likely to be mostly affected by WSDs and as a result over-estimate the maximum permissible WSD power.

We welcome its approach on distinguishing between the 3 clutter environments, but we suggest that separations closer than the proposed threshold must be taken into account. Our analysis shows that in all 3 environment types, that threshold should be 3-4m.

Under these circumstances, we believe that WSD power levels should be about 5dB less in suburban areas and about 7dB less in rural areas. In order to compute the exact figures, the full set of 18 Monte Carlo simulations must be repeated.

Annex C

Overloading considerations relating to amplified TV installations and WSD EIRP Limits

Background

Ofcom proposes an EIRP limit of 4W for WSD to protect against overload of DTT installations. To assess the suitability of such a limit, we need to consider the performance of mast head amplifiers (MHA) and TV Distribution Amplifiers (TVA) commonly used in domestic installations.

Data previously collected as a part of the ICT-KTN Wireless Technology Innovation Centre (WTIC) is relevant to this analysis and is presented in this annex.

Amplifier 3rd order input intercept point

The linearity of an RF system is usually characterized in terms of its third order intercept, which is measured using a two-tone test. Wanted signals at frequencies f_1 and f_2 are applied and the non-linearity manifests itself in the form of unwanted third order inter-modulation products at the system output generated at frequencies $2f_1-f_2$ and $2f_2-f_1$. This results from the compression characteristic of the system, which can be approximated by a polynomial expansion. Second order terms tend to be out of band (f_1-f_2 and f_2+f_1) and so the third order terms tend to be the most significant impairment in most RF applications.

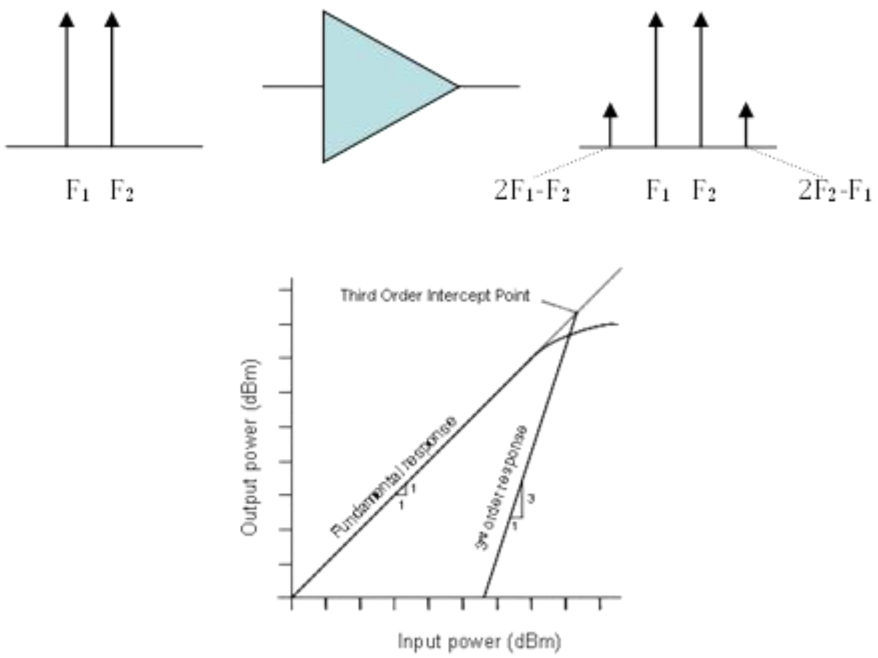


Figure c1. Intermodulation Products from Two tone testing of non-linear amplifiers

The figure of merit for an amplifier is the 3rd order input intercept expressed in terms of the input power measured in dBm. A higher intercept will allow greater levels of LTE or WSD interference to be handled without impairment to the wanted DTT signal.

Measurements

The performance of 6 TV distribution amplifiers and 8 mast head amplifiers was measured at the DTG laboratory in March 2013. The results are tabulated below.

Amplifier Model	Gain (dB)	Input TOI (dBm)
TVA1	10.6	-7.4
TVA2	8.6	-6.3
TVA3	12.5	1.6
TVA4	9.5	0.4
TVA5	18.0	-4.5
TVA6	17.7	7.4
MHA1	10.4	-2.9
MHA2	25.6	-7.6
MHA3	7.6	-0.9
MHA4	20.2	-10.8
MHA5	11.7	-8.7
MHA6	24.6	-9.7
MHA7	24.0	-15.1
MHA8	15.1	4.5

Table c1: Performance of 6 TV distribution amplifiers and 8 mast-head amplifiers

The distribution of performance is given by the following graph:

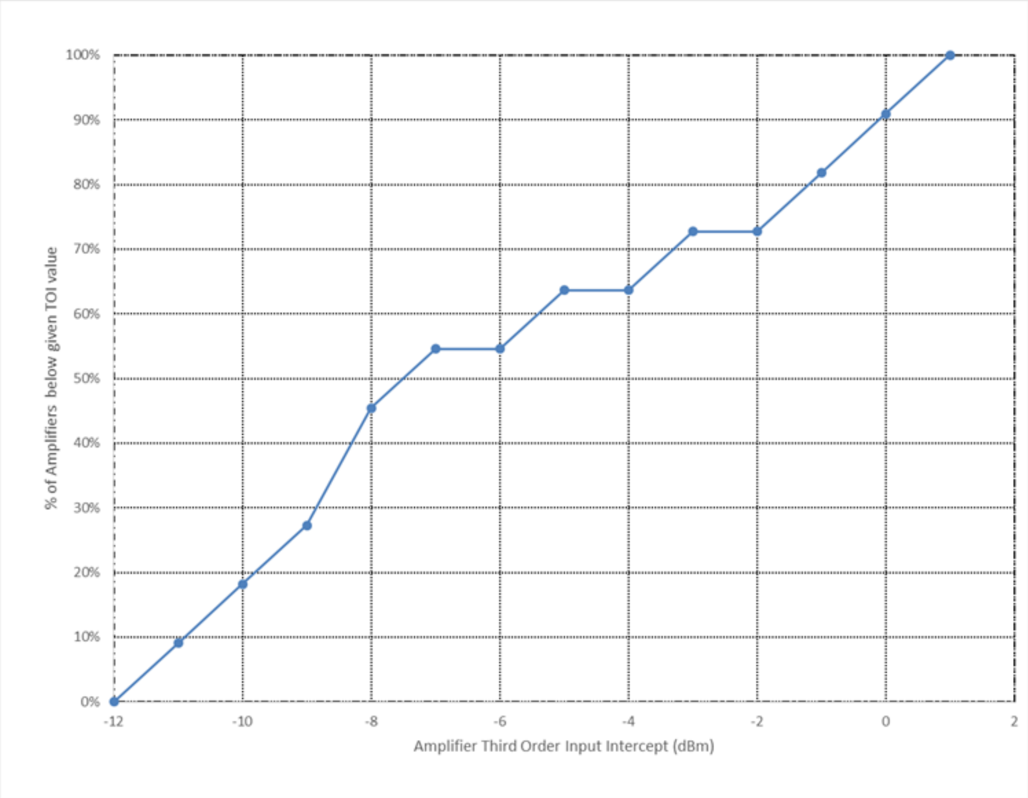


Figure c2. Cumulative Distribution Function for Amplifier Input Intercept

The 30th percentile input intercept is approximately -9dBm, suggesting that 70% of amplifiers will have a performance that exceeds this value.

Effect of amplifier non-linearity on WSD signal

A non-linear amplifier amplifying a WSD signal will generate third order intermodulation products falling into the channels adjacent to the amplified WSD signal. The magnitude of the intermodulation products will be determined by the back-off of the WSD with respect to the intercept point of the amplifier. For example, given a 20dB back-off, the IMD will be 40dB below the amplified WSD signal. Increasing the back-off to 30dB will reduce the IMD to 60dB below the amplified WSD signal.

DTT signals typically require a signal to noise ratio of 20dB, thus any IMD generated in an amplifier must fall at a level at least 20dB below the wanted DTT signal. The minimum DTT signal strength used for planning purposes is -77dBm, thus IMD should be smaller than -97dBm referred back to the amplifier input.

Given an IMD budget of -97dBm and an amplifier intercept of -9dBm, the maximum WSD level at the amplifier input would be -39dBm. For a 4W (36dBm) WSD, the coupling gain to a roof top antenna must not exceed -75dB.

Conclusion

Ofcom is using a 70th percentile coupling gain of approximately -50dB in its co-existence document. This is substantially higher than the value of -75dB required to prevent IMD from degrading a DTT signal at -77dBm. Adjacent channel operation of WSD at 4W will not be compatible with typical amplifier installations at the edge of DTT service area. Operation in the 2nd adjacent channel may be possible, but depends upon higher order compression effects and would require further studies.

Annex D

Comments on averaging the WSD power in the 8 Tier-1 pixels

<u>Background</u>

In paragraph 4.44, Ofcom proposes that the WSD power limit $P_{WSD-DTT}(i, k, F_{WSD}, F_{DTT})$ at each of the 8 tier-1 pixels is calculated and then this power is averaged over k. Then all pixels (k=1..8) will share the same power limit (for each channel F_{WSD}).

We will show that this approach can permit excessive WSD powers, especially in the border areas of two (or more) DPSA zones.

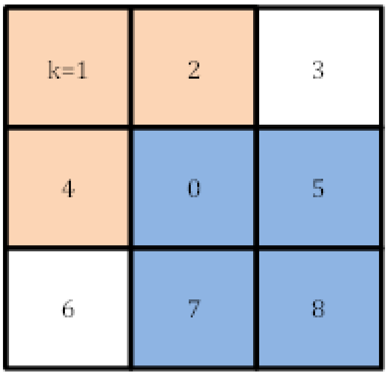


Figure d1: The impact of WSD power levels on pixels in DPSA border areas

In the above figure, pixels with k=1,2 and 4 are in the DPSA of station A, which protects channel 21 and pixels with k=5,7 and 8 are in the DPSA of station B, which protects channel 41. The WSD is located in pixel 0. Pixels 3 and 6 are not populated, hence ignored.

Assuming a class-4 WSD, and m_s =-60, the power limits (taken from Fig 4.13, p 48) are summarised in the table below:

	k=1,2,4	K=5,7,8	Min	Average
Ch 22	0dBm	36dBm	0dBm	18dBm
Ch 40	36dBm	0dBm	0dBm	18dBm

Table d1: Summary of power limits on class-4 WSDs

If the average power is allowed, then the WSD will be permitted to transmit with an EIRP of 18dBm in both Channels 22 and 40, which is 18dB above the value that will significantly interfere with coverage in both channels(pixels k=1..8). Therefore viewers at the borders of the DPSA zones, will completely lose their coverage, even if it is solid and tens of dB above the margin.

A similar but less pronounced problem will occur in areas where m_s varies significantly from pixel to pixel. We therefore propose that Tier-1 pixels are treated in a similar way to Tier-2 pixels, namely:

- Table 4.1(a) is revised so as no Rx aerial angular discrimination is taken into account; and
- The Rx antenna discrimination is considered at a later stage similar to the proposal in paragraph 4.84.

Annex E

Comments on the 7% decrease in location probability

Background

In paragraph 4.61, Ofcom claim that an 1dB increase in the N+I at the 'Edge of DTT Coverage' results in a 7% decrease on coverage probability. While this is roughly the case in a noise limited system, we will argue that this cannot apply to the current DTT network which is limited by 1%-time interference.

The UK DTT network is interference limited

In paragraph 4.57, Ofcom states that a 1dB desensitisation corresponds to an INR of -6dB. It also defines 'Noise' as the sum of thermal noise plus self-interference. If 'Noise' is defined as such, it is the sum of a fixed quantity (thermal noise) and a log-normal random variable (combined DTT interference). Given that the DTT network is largely interference limited, the second term dominates, so it is reasonable to assume that the 'Noise' as defined by Ofcom can be approximated by a log-normal random variable. Therefore, it is not constant within a pixel as thermal noise is, but it is subjected to location variation, just like the wanted signal. This variation was ignored in Ofcom's consultation.

DTT planning rules suggest that within a pixel, each DTT interferer is subjected to a location variation with a standard deviation of 5.5dB. The variation of the combined signal however is much lower, since it is the sum of a large number of log-normal variables. The exact value depends mainly on their relative powers, and a preliminary analysis showed that its standard deviation is (on average) close to 3dB.

If the location variation of the 'Noise' is taken into account, in order to achieve the 1dB desensitisation, the INR should be -6.7dB rather than -6dB suggested by Ofcom. When this is combined with the fact that the carrier to 'noise' ratio has a standard deviation higher than the 5.5 dB assumed by Ofcom, a Monte Carlo simulation has shown that the reduction in coverage probability caused by an 1dB desensitisation corresponds to 5% rather than 7%.

Consideration of where the 1dB desensitisation should be applied

Ofcom mandates that the 1dB desensitisation criterion should be applied at pixels at 'Edge of Coverage', where their predicted coverage probability, for 1%-time interference, is 70%. We do not believe that this approach is cautious. In pixels where the predicted coverage is less than 90%, reception may not be straightforward. This is reflected in JPP's definition of DPSA, where coverage probability between 70 and 90% is classed as 'Primary Level 2', and pixels in this zone are allowed to have a 'Next Best' protected transmitter, in case coverage from the predicted best is not solid.

Eroding 1dB from the margin of these viewers will cause this to deteriorate further. On a daily basis, the 'noise' is usually at its 50%-time level[34], therefore the 'perceived' desensitisation caused by WSDs will be higher.

We suggest that it is more appropriate to apply the 1dB desensitisation criterion to the Edge of 'Primary Level 1' coverage, as defined in the DSPA, i.e. at locations where the coverage probability is 90%.

Monte Carlo simulations have shown that a 1dB desensitisation at 90% coverage probability corresponds to a 2% decrease in coverage probability.

<u>Conclusion</u>

In paragraph 4.61, Ofcom claim that a 1dB desensitisation at the edge of DTT coverage corresponds to a Coverage probability reduction of 7%. They then propose that this reduction should be maintained throughout the DTT service area.

We believe however that it is more appropriate to use the 1dB desensitisation criterion at locations where the coverage probability is 90%. A Monte Carlo simulation shows that this typically equates to a 2% decrease in the coverage expressed in terms of location probability (q). A conservative approach to WSD deployment should limit the maximum degradation in coverage (Δq) to 1%.

Furthermore Ofcom's assumption that thermal noise is the factor which limits coverage is very unrealistic and DTT interference (with the associated location variability) should be used instead.

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[34] 1% Time interference affects DTT reception during periods of "ducting", which typically occur in the summer months. Long-range interference from continental DTT stations will then degrade the reception of UK transmissions. On average, reception is degraded for 3 days per year and additional margin is deliberately designed into the DTT network to allow for ducting.

Annex F

Comment on the algorithm for the calculation of WSD emission limits

Background

In Annex 1, par A1.4, last sentence, Ofcom state that since P_s, U and Z are independent, $A_{(dB)}$ and $B_{(dB)}$ are uncorrelated. This is incorrect, because $A_{(dB)}$ and $B_{(dB)}$ share the same component P_s, so there is a degree of correlation. This can be easily proved using a simple Monte Carlo simulation.

As a result, the sum of A and B cannot be computed using the Schwartz-Yeh approach, which does not take correlation into account.

If the cross correlation coefficient between $A_{(dB)}$ and $B_{(dB)}$ can be computed though, the extension of the Schwartz-Yeh method, presented in [1] can be used. In this document we will show how to compute this coefficient.

Analysis

Following Ofcom's notation, A and B are defined as:

$$A = U / P_s \qquad B = Z / P_s \qquad (0)$$

Since P_s, U and Z are modelled as log normal random variables, A and B are also log normal. If we call u, p, z, a, b the corresponding Gaussians (i.e. $u = 10\log U$, $p = 10\log P_s$, etc.)

By definition the required cross correlation coefficient between a and b is:

$$\rho_{ab} = \frac{cov(a,b)}{\sqrt{D(a)D(b)}} \qquad (0)$$

Where:

- $\text{cov}(a,b)$ is the co-variance of the Gaussians a and b
- $D(a)$ and $D(b)$ are their variances

Writing (0) in the log domain, we have:

$$a = u - p \qquad b = z - p \qquad (0)$$

Then the numerator of eqn. (0) can be written as:

$$\begin{aligned} cov(a,b) &= \langle ab \rangle - \langle a \rangle\langle b \rangle \\ &= \langle (u-p)(z-p) \rangle - \langle u-p \rangle\langle z-p \rangle \\ &= (\langle uz \rangle - \langle u \rangle\langle z \rangle) - (\langle up \rangle - \langle u \rangle\langle p \rangle) - \\ &\qquad (\langle pz \rangle - \langle p \rangle\langle z \rangle) + (\langle p^2 \rangle - \langle p \rangle^2) \\ &= cov(u,z) - cov(u,p) - cov(p,z) + D(p) \end{aligned} \qquad (0)$$

Where $<x>$ denotes the mean of random variable x.

Since u, p, z are assumed to be independent, the three first terms of the above equation are 0, therefore:

$$cov(a,b) = D(p) \equiv \sigma_p^2 \quad (0)$$

Where σ_p is the standard deviation of the wanted signal $P_{s(dB)}$.
The quantity within the square root in denominator of eqn. (0) can be written as:

$$\begin{aligned} D(a)D(b) &= (<a^2> - <a>^2)(<b^2> - <b>^2) \\ &= [<(u-p)^2> - (<u> - <p>)^2][<(z-p)^2> - (<z> - <p>)^2] \end{aligned} \quad (0)$$

The first term in the square brackets can be written as:

$$\begin{aligned} <(u-p)^2> - (<u> - <p>)^2 &= <u^2 + p^2 - 2up> - <u>^2 - <p^2> + 2<u><p> \\ &= <u^2> - <u>^2 + <p^2> - <p>^2 - 2(<up> - <u><p>) \\ &= D(u) + D(p) - 2cov(u,p) \end{aligned} \quad (0)$$

Since u and p are independent, $\mathrm{cov}(u, p) = 0$, and eqn. (0) becomes:

$$<(u-p)^2> - (<u> - <p>)^2 = D(u) + D(p) \equiv \sigma_u^2 + \sigma_p^2 \quad (0)$$

Following the same approach, the second term of eqn. (0) becomes

$$<(z-p)^2> - (z - <p>)^2 = D(z) + D(p) \equiv \sigma_z^2 + \sigma_p^2 \quad (0)$$

Therefore eqn. (0) becomes:

$$D(a)D(b) = (\sigma_u^2 + \sigma_p^2)(\sigma_z^2 + \sigma_p^2) \quad (0)$$

And eqn. (0) becomes:

$$\rho_{ab} = \frac{\sigma_p^2}{\sqrt{(\sigma_u^2 + \sigma_p^2)(\sigma_z^2 + \sigma_p^2)}} \quad (0)$$

Following Ofcom's latest assumption however, Z is not a random variable any more, but a constant. In that case, $\sigma_z = 0$, therefore eqn. (11) becomes:

$$\rho_{ab} = \frac{\sigma_p}{\sqrt{(\sigma_u^2 + \sigma_p^2)}} \quad (0)$$

References

[1] A.Safak : "*Statistical Analysis of the Power Sum of Multiple Correlated Log-Normal Components",* IEEE Transactions of Vehicular Technology, Vol 42, No 1, February 1993.